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BULLETIN
of the
American Association *of* Petroleum Geologists

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AUGUST 1931

GENERAL GEOLOGY OF NORTHEAST MEXICO[1]

J. L. TATUM[2]
Monterrey, N. L., Mexico

ABSTRACT

The writer describes briefly the Tertiary formations in northeast Mexico, gives their areal distribution, and compares them with their Texas equivalents. They are more marine. The regional dip is much greater, affording a better opportunity for study of their outcrops and assuring more certainty in their correlation. The Cretaceous is only mentioned in describing very briefly the changes from the Texas to the Mexican section which occur in this region and their contribution as source material for the younger sediments. The known structures are mentioned and structural trends described, together with the theory as to their probable origin and age of uplift.

ACKNOWLEDGMENTS

This paper is published with the permission of the Continental Oil Company. Credit is due to the following men with whom the writer has been associated for several years: J. M. Hamill, J. W. Fiddler, E. A. Taegel, and Jarvis Garst, and to many other workers in the area. However, responsibility for all statements is the writer's.

INTRODUCTION

There has been comparatively little published concerning the area (see bibliography). Dumble published a paper years ago, which is long since obsolete, on the Tertiary of northeastern Mexico (13)[3]. Böse and Cavings (6), in a bulletin of the Texas Bureau of Economic Geology, de-

[1]Read before the Association at the San Antonio meeting, March 19, 1931. Manuscript received, April 5, 1931.

[2]Continental Oil Company of Mexico, S. A.

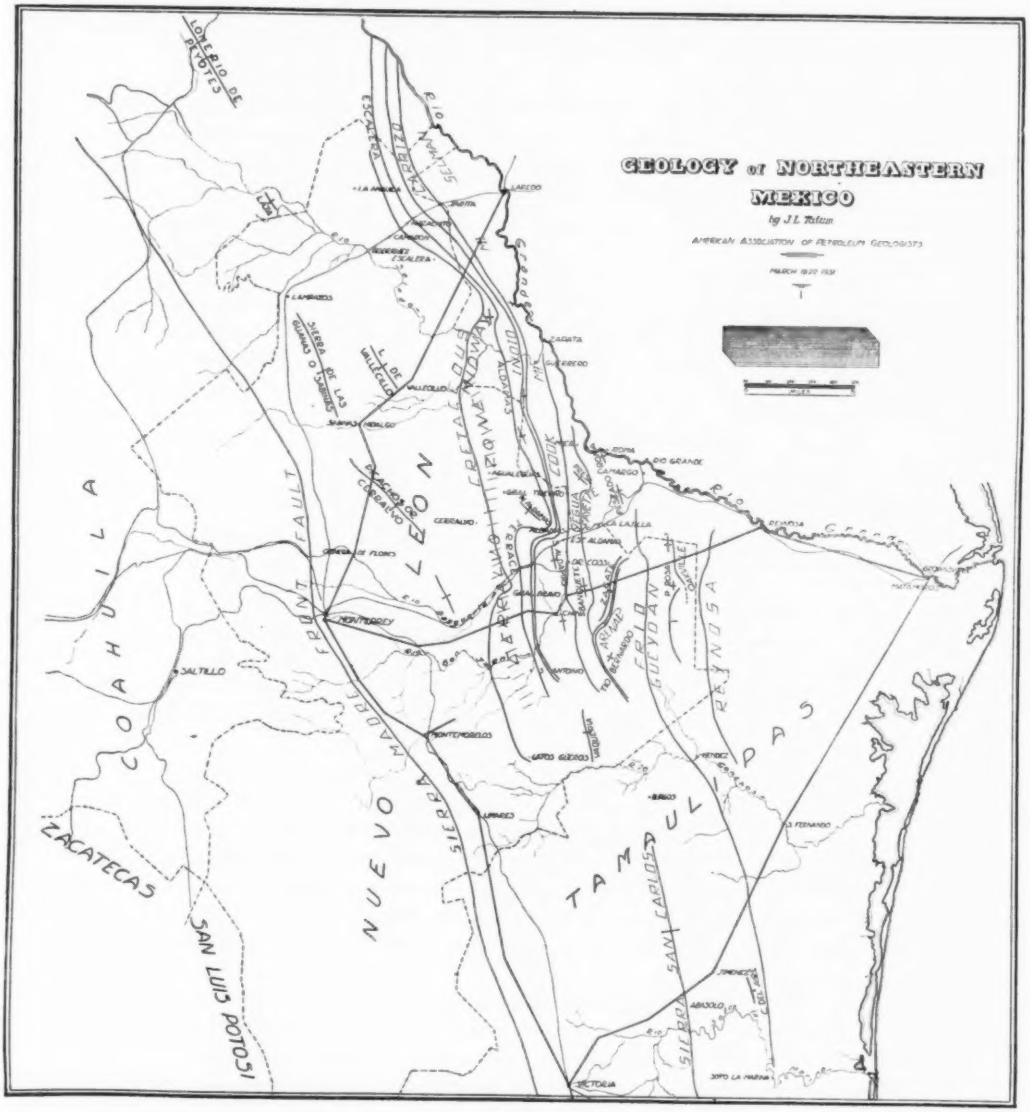
[3]Numbers in parentheses refer to bibliography at end of paper.

scribed the Cretaceous of northern Mexico with brief mention of the Tertiary. Besides a few papers on limited areas, this is all that has been published, in spite of the fact that for the past 10 or 12 years oil companies have had parties working in the area almost continuously. Few geologists agree as to the areal geology because of their different methods of attack and because most either used Dumble's old paper as a base and began their work in different areas, or used the contacts as published by Trowbridge (17), which later work has shown to be incorrect from the Carrizo up. There seems to be almost as much disagreement among the geologists of different companies operating in southwest Texas, because many of their paleontologists have taken their type sections from publications which are obsolete. This is not meant as a reflection on the early workers in the Gulf Coastal Tertiary formations, as all of those who have worked with these formations realize the difficulties in their correlation.

Our information on this area has been gained from continuous work during the past six years. This work consisted of reconnaissance, somewhat sketchy, in parts of Chihuahua, most of Coahuila with the exception of the south part of the state and the more intensely folded areas, all of Nuevo León with the exception of the intensely folded parts, most of Tamaulipas, and detailed work with the aid of aerial photographs over 1,200 square miles in the northeastern part of Nuevo León and of several scattered areas in the same state and in Tamaulipas, in which subsidiaries of the Continental Oil Company have concessions. Work previous to this in the Tampico region and in widely scattered parts of the Republic supplies a background.

Basis for Correlations in Tertiary Formations

Formations in the Tertiary as described and mapped by Deussen (11) and modified by Bailey (1) have been taken as types and their nomenclature used in this report. Lithologic similarity and continuity are the chief basis for their correlation. The writer's knowledge, from personal observation of these formations in southwest Texas, is confined to that part south of the Frio and Nueces rivers. Where the type locality is north of these rivers, our correlations of those formations are probably in error to approximately the same extent as described and mapped by the two previously mentioned authors. However, we believe that the Fayette-Frio contact as mapped by Bailey (1) should be somewhat nearer Roma and that there is probably some Gueydan in the vicinity of Rio Grande City.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by J.L. Tatum
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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COAHUILA
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SOTO LA MARINA
S. FERNANDO
MENDEZ
BURGOS
CERRALVO
VALLECILLO
LAMPAZOS
ESCALERA
SABINAS HIDALGO

FIG. 1

As a key horizon, the Carrizo sandstone was traced continuously from the international boundary near its type locality (17) to a locality approximately 15 miles southeast of the ranch Porvenir, situated on the Rio San Juan southwest of China, Nuevo León, where the typical sands of this formation are replaced by fine sands and shales. Contacts of other formations have not actually been traced continuously, although most, with the exception of the Mount Selman-Cook Mountain contact, have been traced throughout wide areas.

Fossils and micro-fossils have been used to a slight extent as an aid in correlation. Both Hamill and Garst have shown some of our collections to several of the outstanding micropaleontologists of the Gulf Coast and the differences of opinion have been great. This probably results, in a measure, from the fact that geologists of different companies have taken their type sections from different localities which may, in part, have been mapped differently, in many places not even including the same horizons, and from change in the range of the fauna in widely separated areas. Prompted no doubt by this confusion, Wendlandt and Knebel (22) have proposed a new system of nomenclature for the Eocene of East Texas. Possibly this should be undertaken for the entire Gulf Coast; however, it should be done by some organization on some basis on which the geologists interested could agree.

Topography

For descriptive purposes the topography may be divided into three principal divisions: (1) the Reynosa and coastal plain bordered on the west by the Reynosa escarpment and on the east by the gulf, (2) the central area of low rolling hills, broad valleys, and low gravel-covered mesas, and (3) the mountainous area on the west.

Reynosa plain.—From the gulf west to the Reynosa escarpment there is a very gently east-sloping plain unbroken with the exception of the Rio Conchos and the Rio Grande and very shallow valleys amounting to little more than mere swales. These rivers have small tributaries few of which cut into the plain, and none more than a few miles. The escarpment, which ranges from 100 to 300 feet above the levels of the valleys on the west, is irregular and broken by small streams cutting into it from the west.

Central province.—The central province is in turn divided into three sub-provinces, a series of low rolling hills and broad shale-covered flats in the eastern part, a series of long strike ridges known as the Ceja Madre in the north and central part, and a broad low shale-covered area between the Ceja Madre and the mountains, broken by low flat-

topped gravel- and caliche-covered mesas. Some of these mesas extend throughout large areas and the gravel on them effectively conceals the lower formations. One such mesa is south of Piedras Negras, Coahuila, and is bounded on the west by the Peyotes hills. This mesa, like the Reynosa plain, slopes gently eastward and in a wide area is unbroken by streams. There are several such plains, covered by gravel from the mountains and sloping for varying distances from them. These are broken by occasional streams, but otherwise are remarkably smooth and even. With the exception of these and here and there a small isolated mesa, the shale area between the mountains and the Ceja Madre is a region of broad valleys with gently rolling country intervening.

Mountainous area.—The mountainous area is divided into four provinces: the Sierra Tamaulipas and San Carlos, the Sierra Madre Oriental, a series of Front Ranges, and the central plateau region. The Sierra Tamaulipas and the Sierra San Carlos form a single range situated in central Tamaulipas and striking almost due north. The Sierra Tamaulipas, being moderately rugged and reaching an elevation of about 3,000 feet above sea-level, is connected by a low arch, the Mesa Solis, with the Sierra San Carlos. The Sierra San Carlos on the north reaches a maximum elevation of about 5,000 feet above sea-level.

South of Monterrey the Sierra Madre Oriental is composed of closely packed parallel mountain ranges separated by narrow and extremely steep-walled canyons and reaching a maximum elevation of more than 12,000 feet. North of Monterrey the ranges are not so closely packed or so continuous, nor do they reach such heights. The Rio Grande flows around their north end to form the "Big Bend." Beginning with the Sierra Papagayos on the south, about 50 miles east of Monterrey and ending with the Sierra de Burros, west of Del Rio, Texas, on the north, is a series of comparatively low mountains with moderately gentle slopes, approximately paralleling the Sierra Madre, which are here called the Front Ranges. These mountains are structurally distinct from the Sierra Madre Oriental and will be described in more detail later. The central plateau has many mountains, some of which strike at large angles from the Sierra Madre Oriental, separated by broad and some perfectly flat valleys. Many of these valleys, or "bolsons," are the sites of ancient lakes filled with silt and eventually drained by streams which are now cutting into them. The lagoon at Torreon, Coahuila, and the Lago de Jaca on the Coahuila-Chihuahua boundary are existing remnants of these ancient lakes.

Stratigraphy

CRETACEOUS

In northern Mexico the Cretaceous undergoes a radical change from that of the Texas section and has a different nomenclature. Böse and Cavings (6) divide it in accordance with the European system, giving it the European names. In previous literature it has been given a series of names in reference to its lithologic units which are understood by all geologists familiar with Mexico, and these names are used in this article.

TABLE I

Mexican Equivalents of Texas Section

Mexico		*South Texas*
Velasco		Escondido
Papagayos	Mendez	Taylor
		Austin
San Felipe	San Juan	Eagle Ford
Tamasopa	Tamaulipas	Buda Del Rio Georgetown Edwards Comanche Peak Walnut Paluxy Glen Rose Travis Peak

In Table I it may be noticed that most formations have two names in Mexico. This is because they were first named in widely scattered localities and their descriptions were published without certainty of their age. The term Mendez is from the railroad station of that name west of Tampico. The term Papagayos is from the ranch of that name between the Papagayos and Picachos mountains east of Monterrey. Papagayos is the more commonly used of the two and is used in this article. The name San Felipe was taken from the town of that name on the railroad between Tampico and San Luis Potosi. The type locality of the San Juan is in the La Laja hills on Salado River near the boundary between the states of Nuevo León and Coahuila. The name was taken from the Ranch San Juan de la Mucha Agua. The term San Felipe is probably the better known of the two and for that reason is used in this

article. Tamasopa is the original term for the thick series of Cretaceous limestones from the canyon of that name west of Tampico. The limestone in the south fields and in the Sierra del Boca del Abra being very different in character and by some thought to be somewhat different in age (3, 6) from the limestone in the Panuco field and in the Tamaulipas Mountains, the name Tamaulipas was proposed for the latter. Tamasopa being the older term, it is used for the entire series of massive limestones of the Lower Cretaceous underlying the San Felipe.

Tamasopa limestone.—Forming the mountain ranges of eastern and central Mexico is a very thick, ordinarily massive limestone, which geologists associated with the Mexican Survey have considered middle Cretaceous in age, following the European subdivision. This is the Tamasopa. It includes all of the Lower Cretaceous of Texas from the Buda down. Near the International Boundary the Buda, Georgetown, and Edwards have some of the characteristics of the Tamasopa. Del Rio clay either disappears entirely, or, more probably, is replaced by limestone. In a small stream a short distance south of the Oregano ranch house, south of Del Rio, Texas, and west of Eagle Pass, the Del Rio clay is decidedly more calcareous than farther north. On the Hacienda Mariposa there is no break between the Georgetown and the Buda and it is very probable that the Del Rio is a limestone similar in appearance to the formations above and below. In the "control" well near Camarón, southwest of Laredo, a thin shale break of about 2 feet was reported at the horizon where the Del Rio should have been found. In the Sierra Picachos west of Cerralvo, there is about 400 feet of thin flaggy limestone interbedded with shale underlying massive limestone. The shale ranges from black to gray, in places white, the white being bauxitic. This may represent the Del Rio in that area.

The Tamasopa limestone differs considerably in color, texture, and thickness of bedding. It is commonly massive, some beds being several hundred feet thick; however, at places there are exposures of several hundred feet of beds ranging from a few inches to a few feet. Some of the beds have a peculiar nodular structure. The predominating color is a bluish gray, but white and light gray beds are common and in some places the beds are black or nearly black. Most of the limestone is very compact and fine-grained; however, in places it is porous and cavernous. Particularly in the mountains, the beds are cut by small calcite veins and in some places are composed in part of minute crystals of pure calcite. Chert, ordinarily in nodules, occurs in the formation, but is not common throughout. This chert is ordinarily black and much of the gravel de-

rived from the Tamasopa consists of this black chert. Pyrite is not uncommon in the formation and on weathered surfaces is generally altered to iron carbonate appearing as small nodules. In some places the formation is fossiliferous, but ordinarily fossils are scarce and, being almost as hard as the matrix, they are difficult to find and extract. The darker parts of the formation are ordinarily very hard and compact. By dissolving a sample of this dark material in acid, a black, very finely divided residue resulted, which took several hours to settle out of the solution and appeared to be very fine volcanic ash. In the south fields and in the Boca del Abra the formation is a reef limestone entirely different in appearance and texture from the ordinary phases of the Tamasopa. Böse and Cavings (6) report marls interbedded with thin limestone supposedly older than any Cretaceous known in Texas. The same authors report shaly limestone in the Burros and thin series of marl interbedded with limestone near Saltillo of Travis Peak age or slightly older. The thickness of the formation has never been satisfactorily measured except in its obvious thinner phases. West of Victoria, Tamaulipas, it is about 3,000 feet thick and about 4,000 in the Sierra San Carlos. It has been drilled through in the Panuco fields, where its thickness approached the lesser amount. It has been estimated to be as thick as 25,000 feet.

San Felipe.—Within a relatively short distance south of the Rio Grande, the Austin chalk changes in appearance and its lower part is indistinguishable from the Eagle Ford below. The lowest part of the Austin and the Eagle Ford constitute the San Felipe. The San Felipe is identical with the Eagle Ford of south Texas in appearance, differing only in color. The limestone ranges in color from pinkish gray to black. The shales range from a greenish blue to black. In many places where the beds are black, freshly broken fragments give off an odor of petroleum. Both limestone and shale generally show lamination, this being due to thin streaks of very fine sand. This limestone invariably breaks into rectangular flags which are used extensively for building material. The limestone is used for door and window sills and for street curbs in Monterrey and polishes to a glossy black in San Felipe. The San Felipe probably rests disconformably on the Tamasopa. In the San Diego Canal near Oregano, where a contact of the Buda with the Eagle Ford is exposed, the Buda was seemingly subjected to erosion before the deposition of the Eagle Ford, but there is no angular unconformity. Wherever the contact between the Tamasopa and San Felipe was observed, the change in lithology is marked. In the north the for-

mation ranges in thickness from 600 to 1,200 feet. In the south, over the structural "highs" of the oil field, it is somewhat thinner.

Papagayos.—South from Eagle Pass the upper part of the Austin chalk changes within a short distance to gray, compact, poorly bedded shale. This change is noticeable on the east side of the La Laja hills, immediately south of the Don Martin Dam along the Coahuila-Nuevo León boundary. This upper part of the Austin, together with the Taylor, constitutes the Papagayos of the Mexican section. It is ordinarily bluish gray shale very similar to the Taylor in south Texas and contains only a few very fine-grained thin calcareous sandstones. These sandstones do not seem to occupy a definite horizon and in most sections are missing entirely. These beds constitute most of the Upper Cretaceous and are remarkably uniform from the vicinity of the International Boundary at least to central Vera Cruz. They occur throughout the plateau region with comparatively little change except near the western limits of the Cretaceous deposits where they are more sandy. They range in thickness from 2,000 to 5,000 feet.

Velasco.—The type locality of the Velasco is in the vicinity of the railroad station of that name west of Tampico, on the road to San Luis Potosí. In the type locality the Velasco is very similar to the Papagayos, being slightly more sandy and supporting a somewhat denser type of vegetation. In this locality there are no sand beds proper in the Velasco, the sand consisting of fine grains within the shale, which are only noticeable when washing samples of the formation. There is some evidence of unconformity in that area and the faunal change is abrupt. We have never positively identified Velasco as such in the north; however, the assumption is that it is equivalent to the Escondido of south Texas. Within a relatively short distance the Escondido loses its sandy aspect of the Rio Grande region and in the vicinity of Camarón on the railroad from Laredo to Monterrey, is probably represented by a few hundred feet of gray shale, only slightly more sandy than the underlying Papagayos. Southwest of Las Tortillas and east of Vallecillo, the upper part of the Cretaceous is represented by gray shales with a few thin, irregularly bedded shaly sandstones. This sandy phase may represent the Escondido and Velasco in this region. On the old road from Los Ramones to China, at the crossing of the Arroyo Salinas, there are some sandy shales and poorly bedded, shaly fine-grained sandstones, from which Hamill collected *Foraminifera* which he considered Velasco in age. These are probably the beds which Dumble classified as Midway in that region. The thick sandstones reported by Böse and Cavings (6) and Kane, be-

tween Saltillo and Paredón and the Cárdenas beds (4) in the state of San Luis Potosí, probably represent the Escondido.

EOCENE

The Eocene in northern Mexico is similar to that described in south Texas. It differs only in being somewhat thicker and it is practically all marine.

CRETACEOUS-EOCENE CONTACT

The contact between the Cretaceous and the Eocene crosses the Rio Grande about 10 miles below the town of Guerrero, Coahuila. From there it strikes slightly east of south to a place a few miles east of the ranch La Anguila, where Midway sandstones are exposed east of a large lagoon; from there it strikes more toward the east, crossing the railroad from Laredo to Monterrey between the stations of Huisachitos and Camarón to a place on the south side of the Ceja Madre north of Las Tortillas, and from there turns southward, passing between the ranches of El Aguila and Zancudo, and crosses the Rio Salado a short distance above the town of Las Tortillas. From there it strikes almost due south, crossing the Rio Sabinas at a place known as Piedras Pintas and from there south to a hill known as Cerro Colorado west of Los Herreras. It crosses the Rio Pesquería south of the last mentioned place, where it swings sharply southwest for a few miles and again swings south crossing the national highway from Monterrey to Matamoros, about midway between Los Ramones and the Ranch Puerto del Agua, where it forms a prominent scarp. From there it swings southeast, passing east of the town of Santa Engracia and immediately south of the Ranch Gatos Güeros northeast of Linares, and from there swings east around the north end of the San Carlos Mountains. From a few miles east of Cruillas it swings south and it occurs at the base of the Cerro del Aire northeast of Abasolo, crossing Soto la Marina River about midway between Abasolo and the town of Soto la Marina. In many places the contact is obscured by alluvium or gravels, but most of it is well exposed.

Midway.—The Midway in this area is divisible into two zones: the lower consisting of sandstones and brown-weathering clays, and the upper consisting of brown-weathering clays which contain many ironstone concretions. The lower sandy zone is in many places either missing or overlapped by the upper clay zone. These lower sandstones, which ordinarily contain many fossils, mostly *Venericardia*, are well described by Trowbridge (17) from his outcrop along the Rio Grande. They do not differ essentially from these descriptions in northern Mexico. North

of Las Tortillas, on the north flank of the Salada arch, they occur only as lenses on the Eocene and Cretaceous contact. At Las Tortillas the lowest Midway is blue shale, very similar to the Papagayos and determinable only by its fossil content. South of Las Tortillas, in the vicinity of the ranch La Lajilla, the lower sandstones are well developed, but fossils are somewhat scarce. About a mile west of the ranch, there is a thick medium- to coarse-grained sandstone capping a lone mesa overlying about 10 inches of fossil soil on top of Cretaceous clay. These lower sandstones are well developed from this point south. The basal member is seen on the road from Cerralvo to Los Herreras, where it consists of sandstones containing fossils in profusion. This same sandstone caps the hill known as the Cerro Colorado between Los Herreras and Los Ramones. It is filled with fossils here also. In the vicinity of Gatos Gueros there are sandstones containing plentiful *Venericardia* overlying the Cretaceous. We have never been able to measure the Midway with any degree of accuracy. Until such date as the micropaleontologists can agree on the thickness of this formation from the wells being drilled through it, we assume it to have a minimum thickness of 1,500 feet.

WILCOX GROUP

Indio formation.—The Indio near the Rio Grande is entirely similar to that in south Texas. In the section south of Laredo on the road between the Ranch Sauz and Las Tortillas, it consists of about 2,000 feet of sandy shale with thin beds of fine- and medium-grained, generally impure sandstones, a few of which contain fossils, and some thin impure limestones. It contains some large calcareous concretions and some small ironstones. The clay in many places contains gypsum, and both the sandstones and shale ordinarily have a small amount of mica. The sandstone is ordinarily fine-grained, generally gray, but in places brown, and generally weathers brown. Many fossils were first observed in the Indio north of the Ranch Escalera, where there are a few beds containing *Venericardia* and some small oysters. The fossils increase gradually southward to the vicinity of Los Herreras, where they form a prominent fossiliferous zone that continues farther south. On the road to Monterrey, west of China, there is about 1,000 feet of soft, fine-grained, gray sandstones near the base of the formation containing a great profusion of large *Venericardia* called by Dumble *Venericardia popocapensis.* Overlying these fossiliferous beds west of China, there is a series of gray shales which weather brown, containing some fine sand and small iron carbonate concretions and thin beds of fine-grained flaggy sandstones.

These beds are similar in appearance to the Indio in the north. In this area they are 650 feet in thickness. The total thickness of the formation west of China is about 2,000 feet, the same as that south of Laredo.

Carrizo sandstone.—The Carrizo sandstone, as in south Texas, consists of a thick series of massive fine- to coarse-grained, white, gray, and red sandstone which ordinarily contains layers and lenses of sandy gray shale which weathers brown. The sandstone is generally composed of clear quartz grains many of which are stained red by the cementing material. It is ordinarily cross-bedded. Due to differences in the firmness of the cementing material, castellated forms are common. This formation has been used as a key horizon in mapping the Eocene in northeastern Mexico. It was traced continuously from its outcrop on the Rio Grande to a locality 15 or 20 miles southeast of the ranch of Porvenir on San Juan River, south of China. Throughout almost all this area it dips at a steep angle, 5°-15°, and its general appearance is such that it can rarely be confused with any other formation in the area. Some of the sandstone in the base of the Midway, and a few sandstone lenses in the Cook Mountain, have a similar appearance. These beds can be distingushed everywhere by their relationship to the beds above and below, and there is ordinarily no reason to confuse them with the Carrizo. This formation is reported as being non-marine in Texas, and, for the most part, is non-marine in this area. However, sandy shale interbedded with the sandstone commonly contains *Foraminifera.* These may possibly be derived from older formations. Trowbridge gives its thickness on the Rio Grande as being about 400 feet, and in the vicinity of Sauz, on the road from Laredo to Las Tortillas, it has a measured thickness of 850 feet. West of China it has a measured thickness of about 400 feet. West of China the sand becomes somewhat more fine-grained and there is much more shale in the formation. Southeast of the ranch Porvenir the sandstones are thinner and fine-grained and the shales are even more plentiful. We have not determined whether the formation thins out entirely southeast of this place or is replaced by shale.

Bigford formation (?).—Trowbridge (17) describes a formation above the Carrizo, along the Rio Grande, similar in appearance to the Mount Selman above, as Bigford. His chief reason for the separation of this formation from the Mount Selman is that he considers it as occurring in continuation of the strike of the Carrizo from the north, and, for that reason, thinks that it replaces part of that formation. In the vicinity of Carrizo Springs the dip of the Carrizo is very low, only a few feet to

the mile. Immediately southward, where it crosses the Rio Grande, the dip is 4° or 5°, and the width of the outcrop is sufficiently great to contain a full thickness of Carrizo, as found in its type locality. For this reason the writer considers the Bigford a misnomer.

CLAIBORNE GROUP

Mount Selman and Cook Mountain.—In this area the Mount Selman and Cook Mountain dip steeply and although the formations are divisible on the same basis as in south Texas, the writer has not divided them except locally. In appearance they are essentially the same as described in south Texas. However, the Mount Selman is marine in at least part of the area, and the Cook Mountain is both marine and non-marine. In places the formation contains many fossil leaves and in some places thin bands of lignite. Many of the sandstones contain fossils, chiefly *Venericardia*, and a few oysters. In well samples it contains *Foraminifera* in profusion, but on the surface in many places they are leached out by evaporating surface waters. In general, the Cook Mountain contains less glauconite than in Texas. In the vicinity of Aldamas and China a few beds contain sufficient glauconite to give them a red color on weathering, which is common in south Texas. South of China the red-weathering bed becomes somewhat more common. These two formations have an average thickness of about 2,100 feet.

Yegua.—East of Aldamas and China is a thick series of greenish and gray clays which weather brown, contain many ironstone concretions and some thin ironstone bands and here and there medium- to fine-grained sandstone. These overlie a heavy massive sandstone in the upper Cook Mountain, entirely different in appearance from the sandstone in the Yegua. In this area the formation is ordinarily marine; it contains many small fossils and here and there a thin bed of small oysters. Gypsum is common, occurring as selenite. Between the San Juan and Rio Grande, the formation is somewhat more sandy and contains more oysters. However, it retains its distinctive color on weathering and the clays in the formation are similar in all respects to the clays of the south. It contains a few lenses of chocolate-colored clays, but these are not common. The general aspect of the formation is very similar to that as mapped by Deussen east of Cotulla, in La Salle and McMullen counties. From San Juan River to a locality approximately 25 miles southeast of China, the writer has mapped this formation with as much detail as possible, which in most places is much more detailed than can be shown by the accompanying small-scale map. North of this river we have not

traced the contacts throughout an extended area. The brown-weathering clays at Zapata, Texas, we consider as equivalent to this formation, and not Cook Mountain, as Trowbridge (17) maps them. The heavy sandstones between Roma and Rامereño the writer considers above this formation and within the Fayette. The large oyster beds at the town of Mier are in the Fayette and the writer has placed the Fayette-Yegua contact about a mile west of that town. There is much disagreement about the Yegua in this area, but regardless of the relative age of the Yegua as shown on the map, it is unquestionably a lithologic unit and distinctive from the formations above and below. It has a measured thickness of about 1,700 feet on the San Juan.

JACKSON GROUP

Fayette.—The Fayette in this area consists of a thick series of light-colored soft and poorly bedded sandstones containing oysters and silicified wood interbedded with gray sandy shales. Near the Rio Grande the oysters are large and very plentiful. Southward, the oysters become smaller and comparatively scarce. In appearance the formation is very similar to the Cook Mountain and there is no single characteristic by which they might be distinguished. Generally the Fayette is somewhat softer than the Cook Mountain, contains less fossils, with the exception of oysters, and silicified wood is somewhat more common. It contains less glauconite than the Cook Mountain, but it can not be identified positively by any of these characteristics. In places it contains a bed of chocolate-colored clays and toward the top the chocolate clays are common. Where it occurs in contact with the Cook Mountain it is impossible to distinguish the two formations with any degree of certainty. South of the old road from China to Matamoros only the top of the formation occurs, which more properly belongs to the local formation which we have called the Arenal. This formation has a measured thickness of about 2,300 feet along San Juan River. It disappears entirely toward the south, except as mentioned later.

Arenal formation.—Along the fault which forms the east side of the Zacate structure, there is a much distorted series of chocolate-colored clays with fragments of soft medium-grained yellow and gray sandstones. Near this fault the sandstone occurs as boulders, angular and ranging in size from a few inches to several feet. Toward the southeast these chocolate-colored clays continue, and south of the Matamoros-China road are interbedded with sandstones similar in texture to that already described, but occurring in beds rather than boulders. Farther south,

in the vicinity of Los Cerritos, the formation is represented by massive sandstone at the base, by some volcanic ash, and chocolate-colored clays. At this place it is probably not more than 200 feet in thickness. Northeast of Ochoa the chocolate clays and soft sandstones which we have mapped as Fayette are probably the equivalent of this formation.

Frio.—Overlying the Arenal, a series of greenish clays contains much gypsum and some thin beds of very fine-grained sandstones, many of which dip at steep and variable angles. The outcrop of this formation ranges in width from almost nothing near the Tamaulipas-Nuevo León boundary to more than 30 kilometers east of China. It forms a typical topography consisting of low rounded hills and broad grass-covered flats. Water holes in streams that cross this formation are invariably impregnated with salts, and salt-loving plants are abundant along the outcrop. Bailey's description of the Frio in south Texas applies to the formation in this area. Macroscopic fossils are rare, but *Foraminifera* are plentiful. However, there are zones in which these are absent also. Toward the top of the formation the clays become lighter in color and are similar in appearance to some of the clays in the Gueydan above. North of the Tamaulipas-Nuevo León boundary, as far as the railroad east of Ochoa, the Frio is almost completely overlapped by the Gueydan above. There is a broad silt-covered valley between the Gueydan scarp and the Fayette on the west. Toward the base of this scarp east of Ochoa, we found a small exposure of clays similar to the Frio. North of this place we have done very little work and, in trips across that area, have not noticed any beds that are unquestionably Frio. Northwest of Rio Grande City, Texas, and east of Roma, the Frio is well developed. It seems probable, however, that the contact in that area between the Fayette and the Frio should be somewhat nearer Roma. The clays northeast of the Texas Company well at Roma look very much like Frio.

OLIGOCENE

Gueydan.—Unconformably overlying the Frio is a thick series of beds composed mostly of volcanic material, which are similar to the beds described by Bailey in south Texas as Gueydan. As already mentioned, these beds completely overlap the Frio in places. The basal member consists of a medium-grained sandstone locally silicified, and in places very fossiliferous, which forms a prominent scarp easily traceable from the area north of the Tamaulipas-Nuevo León boundary, south through Mendez and around the east side of the San Carlos Mountains to Soto la Marina River, and from there, it is reported, considerably beyond

Tampico, where it is the basal Oligocene (6, 12). At Mendez the basal member is a reef limestone forming a high westward-facing scarp. This formation is not readily divisible into three members, as Bailey (1) divided it in south Texas, but, with the exception that in this area the formation is fossiliferous and the material becomes less obviously volcanic in origin southward, Bailey's descriptions of it in south Texas could very well apply here. Beds of pure volcanic ash are common, and in the vicinity of Huisachitos, near the Nuevo-León-Tamaulipas boundary, there is a thick bed of white volcanic ash at the top of the formation. Near the middle of the formation there is a comparatively thick series of coarse- to medium-grained sandstones, poorly bedded, but ordinarily fairly massive, which forms a prominent scarp that is traceable for miles. North of Puerto Rosa, near the eastern boundary of Nuevo León, the scarp formed by these sandstones is covered by a thick bed of gravel composed mostly of chert pebbles derived from the Tamasopa and with the same dip as the underlying sandstones. At this place this scarp swings sharply east and is broken by a stream cutting through it. From here it continues south, forming a high westward-facing scarp which reaches an elevation of more than 1,000 feet above sea-level. The writer has never been able to determine to his own satisfaction whether these gravels are a part of the formation or younger in age. Southward, east of the San Carlos Mountains, the formation contains many beds of gravel derived from the near-by Tamasopo. About midway between these sandstones and the base of the formation there is another ridge-forming sandstone interbedded with green bentonitic clays. Large oysters more rounded and smoother than the large oysters of the Eocene occur commonly within this horizon. There is no question but that the Gueydan in this area is the northward continuation of beds of the Soto la Marina region definitely placed in the Oligocene (6, 12) by different authors.

MIOCENE AND YOUNGER

East of the Ranch Huisachitos, overlying a thick volcanic ash bed, there is a series of medium- to coarse-grained sandstones interbedded with clays which weather yellow. These are placed tentatively in the Oakville. The basal member of this series is coarse massive sandstone, ordinarily lenticular and commonly forming prominent but short strike ridges. East of Huisachitos there is an outcrop of siliceous material which appears to be a sill, similar to the chalcedony of Duval County. This material also occurs in several places somewhat higher

in the section. Above these sandstones and clays there is an area several miles wide in eastern Nuevo León and immediately east in Tamaulipas and below the Reynosa escarpment, which is covered by a light-colored sandy soil supporting a comparatively dense vegetation in which exposures are rare. There seems to be some volcanic material, probably thin beds of ash, but beyond this it has been impossible to gain a very good idea of the lithology. Above this the Reynosa forms a scarp broken and not so prominent as in south Texas, but composed essentially of the same materials.

Gravel terraces.—Along the San Juan there are three distinct terraces, the upper being the most prominent, covered with gravel derived from the Tamasopo on the west. These gravels are similar to those of the Reynosa and by many have been called Reynosa in age. It is obvious, however, that they are of different ages. The gravels mentioned as occurring on sandstone ridges within the Gueydan may represent ancient terraces. The higher hills throughout the Frio outcrop are of approximately the same elevation and are covered with a light coating of chert gravel, much finer than that ordinarily found covering river terraces or within the Reynosa. Between Huisachitos and Puerto Rosa there is a hill of massive Oakville sandstone in which are ancient potholes filled with gravel, indicating the bed of an ancient stream flowing northward, comparable in size with the present San Juan. Along the Arroyo Lobo, south of Zacate Station, and in several of its larger tributaries, elephant teeth and tusks were found in stream alluvium. The occurrence of *equus* teeth in gravel thought to be Reynosa near Rio Grande City may be in younger terrace gravels, which, if they occur at the approximate elevation of the present Reynosa, would be indistinguishable; therefore, this occurrence does not necessarily prove the Pleistocene age of the Reynosa. The occurrence of elephant remains in stream alluvium undoubtedly younger than Reynosa lends strength to this view.

Structure

SIERRA MADRE ORIENTAL FAULT

The Sierra Madre Oriental is an enormous thrust fault with massive limestone of the Lower Cretaceous standing on edge and forming high and closely packed mountain ranges with very steep intervening canyons. North of Monterrey the strike of these ranges changes somewhat and they are not so high and not so closely packed. In the north the individual mountain ranges are simple folds on the ends passing into thrust faults in the center. The Cerro de la Silla at Monterrey is a

limestone range parallel with, and in front of, the Sierra Madre fault proper. On its west flank it shows underthrust from the west. Paralleling the Sierra Madre fault and for several miles toward the east, partly metamorphosed shales dip steeply toward the mountains. This is characteristic of thrust faults of great magnitude. This enormous thrust fault undoubtedly has affected the folds on the east, but the extent and relationship has not been determined.

FRONT RANGES

Some distance east of the Sierra Madre and approximately paralleling it, is a series of hills and mountains consisting of comparatively simple anticlinal folds. On the south these begin with the Sierra Papagayos, including the Sierra Picachos, the Sierra Lampazos, the Sierra de Vallecillos, the Lomas de la Laja, the Peyotes Hills, and the Sierra de Burros. The Sierra de Vallecillos is a low parallel fold east of the Sierra de Lampazos and is not so high as the latter. The dips on these folds are comparatively gentle, few being more than 10° on the east flank and averaging about twice that on the west. The steeper west dip is probably a result of the Sierra Madre movement. West of these ranges are broad basins in which the shales of the Upper Cretaceous are much disturbed. In a few places the Lower Cretaceous is exposed in complicated folds. These ranges seem to have acted as an effective barrier against the Sierra Madre movement. The difference in the intensity of the movement on either side of these Front Ranges is indicated by the following analysis (20) of coal from Eagle Pass east of the Peyotes and from the Sabinas basin west of the same hills.

Analysis of Eagle Pass Coal	*Per Cent*
Moisture	2.50
Volatile hydrocarbon	40.60
Fixed carbon	42.75
Ratio	1.05
Ash	14.18
Color of ash	Light brown
Coke	Coherent hard

Analysis of Coal from Santa Rosa Region	*Per Cent*
Moisture	5.75
Coke	77.147
Ash	3.53
Specific gravity	1.41
By computation this coal should have	
Fixed carbon	73.617
Volatile hydrocarbon (approximately)	17.103
Ratio	4.3

TAMAULIPAS ARCH

In central and southern Tamaulipas there is a range of low mountains known as the Sierra de Tamaulipas on the south and the Sierra de San Carlos on the north. These are connected by a low arch, the Mesa Solís. These mountains form a low broad arch, with a porphyry core appearing in the San Carlos. The limestone is reported to have been deposited on this porphyry rather than the porphyry intruded into the limestone. This arch continues southward and the Cacalilao and Panuco fields are situated on it. It is not traceable toward the north, but there is no good reason to believe that it does not extend northward as it does southward. On the east flank of the continuation of this arch toward the south, is the famous Golden Lane. The producing horizon in the Golden Lane is a reef limestone with a fault on the west side. West of the Cacalilao-Panuco fields, at the foot of the Sierra Madre, there is a long fault scarp expressed as a low range known as El Abra and composed of a reef limestone reported to be of the same age as that of the Golden Lane. The limestone in these two localities is entirely different from the ordinary Tamasopo and is reported to be somewhat younger in age (6). East of the Mesa Solis, in the vicinity of Abasolo, there is a high hill known as the Cerro del Aire, which is composed of a reef limestone supposedly of Upper Eocene age (6). The Golden Lane and El Abra range were undoubtedly fault scarps on which reef-forming limestones were deposited. Their relationship to the Tamaulipas arch indicates that they were faults facing this arch which has acted as a positive segment from at least early Cretaceous time to the present. The Cerro del Aire was a similar fault scarp during Upper Eocene time and may also have been one during the Cretaceous. The position and strikes of the Zacate and Tio Bernardo structures in northeastern Nuevo León in respect to the prolongation of the axis of the Tamaulipas arch suggest that these also are fault scarps on the flank of that arch. The structures on the east along the Tamaulipas-Nuevo León boundary are probably intimately connected with this same positive structural feature.

ESCALERA-ALDAMAS TERRACE

Beginning with the Salada arch on the north, paralleling the outcrop of the Carrizo sandstone, there is a zone ranging in width from 5 to 10 miles, of exceptionally steep dips ranging from 5° to 20° and accounting for a drop of almost 5,000 feet within a few miles. Northwest of Aldamas Station, the strike of the beds on the flank of this terrace swings sharply west to the vicinity of Herreras and from there

turns southward and steep dips extend beyond San Antonio, south of San Juan River. On top of this terrace the beds are comparatively flat. On top and along the edge of the terrace there are several well known domes and plunging anticlines. Among these are the Escalera anticline or Salada arch, the Barreta anticline, the Guerrero dome, the Ojo de Agua dome, and the north Aldamas anticline. In continuation of the axis of the terrace and in the re-entrant formed by the swing of the axis of the terrace toward the west, in the vicinity of Los Aldamas, is the plunging structure known as the South Aldamas anticline. South of this is another structure with the same general strike, which is here called the China anticline. This is a low anticline immediately east of the town of China and probably does not have more than 100 feet of west closure. It is more in the nature of a small terrace than an anticline proper. The Vaquiría anticline, seemingly a much larger structure, is south of this and on the same strike. On the flank of this terrace, and distinct from the South Aldamas, China, and Vaquiría anticlines, there is here and there a small fold whose relationship to the other folding in the area is obscure. The La Presa anticline on which the Ohio-Mex is now drilling, and the Banquete anticline east of General Bravo, are representatives of these. The Banquete anticline is a simple fold 5 miles in length, with a west reversal of about 150 feet. It is closed on all sides, with the possible exception of the northwest, and on this side there are not sufficient data to determine whether it is closed here also.

CERRALVO ZONE

Between the Escalera-Aldamas terrace and the Front Ranges, there is a narrow zone characterized by sharp folds and many faults. On the north this begins with a faulted zone south of Las Tortillas, in the vicinity of the ranch La Lajilla, near the Cretaceous-Eocene contact, and is practically continuous southward beyond the Ranch San Antonio, south of San Juan River. Between Los Herreras and Ramones, this feature converges with the Escalera-Aldamas terrace where the latter turns sharply toward the west. This zone follows closely the Cretaceous-Eocene contact, being mostly in the area covered by the Midway. The well being drilled by the Cía. de Petróleo Mercedes, subsidiary of the Standard of New Jersey, between Cerralvo and General Treviño, is on a fold within this zone.

PESCADA AND ROMA STRUCTURES

Paralleling the Escalera-Aldamas terrace on the east, west and south of Roma, Texas, there are two known structures designated, re-

spectively, the Roma and Pescada anticlines. The Pescada anticline is the better defined of the two. Several hundred feet of closure is indicated by good exposures showing west dips in San Juan River west of the axis. The Pescada structure plunges south before reaching the railroad. Two wells drilled on this structure, one to a depth of 3,600 feet and the other slightly deeper than 3,700 feet, have had good showings of oil and gas. The first well drilled by the Control de Administración del Petróleo Nacional had excellent showings of both oil and gas, but the well was junked before testing. The second well, drilled near by, by the San Juan Drilling Company, slightly higher on the structure, reported several showings of gas. These wells were commenced a few hundred feet below the top of the Fayette.

ZACATE AND TIO BERNARDO STRUCTURES

Beginning near the point of the V formed by the boundary line between the states of Nuevo León and Tamaulipas, almost due south ot Camargo, there is a faulted anticline 25 miles in length, striking S. 20° W. This structure has a fault on the east side, downthrown toward the east, whose displacement is at least 1,000 feet. It has a closure on the west between 1,000 and 2,000 feet. The exact age of the beds exposed on the structure is not known. They are probably lower Fayette; if so, they are overlapped on the north and west by younger Fayette. Two core machines are being operated on this structure and within a few months more definite information is expected as to the age and relationship of the beds in that area. On the east, parallel with the fault, there is a narrow band of sandstones and shales which the writer has called Arenal and which are probably equivalent to upper Fayette in age. In some places these Arenal beds are missing and the Frio is faulted against the sandstones covering the structure. The upper Fayette beds were very slightly affected by the folding in this structure and may not have been deposited over it. However, there certainly was movement along the fault, at least after the deposition of the Frio. Whether or not the normal thickness of Fayette was deposited east of this fault, there seems to be no means of knowing. As mentioned in the discussion of the Tamaulipas arch, this structure is probably more nearly related to that feature than any other structural feature of the region. The writer's theory is that it is a fault scarp facing the plunging end of the Tamaulipas arch. If such is the fact, the fault has probably existed since early Cretaceous time, and reef limestones may have been formed on it during Cretaceous or possibly during early Eocene time.

Southeast of this structure there is a sandstone hill within the Frio flat, in which sandstones foreign to the Frio, probably Fayette, are exposed. These sandstones dip 7° toward the west, and strike N. 20° E. The hill is only about 800 meters in length and is surrounded by a broad plain, covered with soil derived from the Frio. From its strike it is probably a fault downthrown toward the east, similar to the fault on the east side of the Zacate structure, but much more limited in extent. The dips in the sandstones along the Frio-Arenal contact on the west indicate that this represents an uplift of not less than 500 feet. It is possible that this structure may be a simple anticline rather than a faulted one, as the writer believes. This is the Tio Bernardo structure.

For several miles east of the Zacate fault, the Frio is very much distorted. With the exception of a few miles of Frio overlapped near the north end of the Zacate structure, the eastern boundary of the Frio corresponds with the general strike of the region. As mentioned under Stratigraphy, in the south the outcrop of the Frio is more than 30 kilometers in width. It has been impossible to determine the structure in that region, and until the thickness of the Frio can be ascertained, there is little on which to base a theory. From the width of its outcrop, we assume that in part it covers a broad arch or terrace.

HUISACHITO STRUCTURE

Along the Gueydan-Oakville contact near the northern boundary of Nuevo León, there is a hill made up of volcanic ash with exceptionally steep dips along the Gueydan-Oakville contact on the east, immediately east of the Ranch Huisachitos. On the west side of this ridge, the writer and his associates have plotted many low west dips. These dips were found in steep gullies cutting into the ash on the west side of the ridge. There is some question as to whether or not these are true dips, as the apparent bedding in the ash may be the result of washing, and we were unable to continue the dips or close the structure toward the south. It is reasonable to assume, however, that the steep dips in the Oakville mark either a sharp terrace or an anticline.

PUERTO ROSA STRUCTURE

In the vicinity of the ranch Puerto Rosa there is a dome-like structure within the re-entrant formed by the swing of ridge-forming sandstones of the middle Gueydan on the east. Exposures are so poor in that area that it is impossible to define the structure other than to recognize its existence. South of this place there is a long high ridge composed

of sandstone of the middle Gueydan, capped by gravel, slightly convex toward the west, and with a pronounced east dip slope, which reaches an elevation of more than 1,000 feet above sea-level. This probably represents some sort of structure, perhaps a fault, which could not be determined for lack of exposures.

In Tamaulipas, near the northeast corner of the state of Nuevo León, the Campañía de Petróleo Mercedes is drilling a well as a result of geophysical work. Exposures are such that it is impossible to determine the structure from the surface and the results of the geophysical work on the basis of which this location is made have not been made public.

TECTONICS AND GEOLOGIC HISTORY

Little information is available on which to base pre-Cretaceous geology or geography. There are old beds somewhat metamorphosed and similar in appearance to the Marathon series of West Texas underlying the Cretaceous in northeastern Chihuahua. There are Permian limestones in Chihuahua and Coahuila, and Jurassic has been reported in the mountains south of Monterrey (6). Marine Triassic and Jurassic (8) have been reported in Zacatecas. Porphyry, older than the Cretaceous, is reported in the San Carlos Mountains, and arkose in the Ohio-Mex wells west of Del Rio. Böse (5) postulates a Jurassic continent in northeast Mexico. The continent, according to him, extends from the north, southward, with a peninsula extending south, coming to a point just east of Torreón. From Torreón the shore line extends slightly north of east for almost a third of the distance across the state of Coahuila, thence northeast toward Cuatro Ciénegas, thence eastward to Monclova and Lampazos. He does not delineate it farther. In wells drilled on the Tamaulipas arch in Panuco and Cacailao Jurassic was reported underlying the Cretaceous. Nothing definite has been made public in regard to the Jurassic in these wells, but information now available indicates that they were mostly red shales and coarse sandstones. Whatever land masses existed in Lower Cretaceous time were probably low, as almost all of the Lower Cretaceous is limestone and little of the Upper Cretaceous, with the exception of the Eagle Pass beds and the Cardinas series, contains coarse material.

Between Cretaceous and Eocene time, the continent was uplifted and occupied approximately its present outlines. There is no evidence that the great mountain ranges had as yet begun to be formed. There is almost no material derived from the Lower Cretaceous in the Eocene of northeastern Mexico. The Tamaulipas arch, as mentioned before,

has probably been a positive segment at least since early Cretaceous time, and the porphyry in the San Carlos Mountains is evidence that it was such probably during Jurassic time also. Upper Eocene east of the San Carlos Mountains has conglomerates derived from the Lower Cretaceous in the near-by mountains. This, together with the lack of material derived from the Lower Cretaceous in the Eocene of the north, is evidence that the Tamaulipas arch was uplifted before the Sierra Madre began to be formed. Conglomerates derived from the Lower Cretaceous occur intermittently in almost all the beds above the Eocene east of the San Carlos uplift. These mountains have therefore probably existed as such since late Eocene time. As mentioned in Stratigraphy, there may be a gravel bed in the Middle Gueydan. The occurrence of this gravel, however, is as near to the San Carlos as to the Sierra Madre, and should it be an inter-formational deposit, this would not necessarily prove that it was derived from the Sierra Madre. The first positive evidence of the uplift of the Sierra Madre is the gravels of the Reynosa. The evidence seems to indicate positively that the Sierra Madre was not formed until after the Eocene and may not have reached anything like the present height until Reynosa time. The Reynosa is excellent evidence that the movement forming the Sierra Madre, if not initiated shortly before that time, certainly culminated then. The source of the thick sandstones of the Eocene is uncertain. They may possibly have been derived from Upper Cretaceous beds similar to those in the Eagle Pass basin from the area now occupied by the Sierra Madre, or they may have been derived from older beds much farther west. The shales of the Eocene may well have been derived from the Papagayos.

There are basaltic plugs on the north end of the San Carlos Mountains. There is some volcanic activity on the south side of the Sabinas basin and some in the mountains south and west. The volcanic material in the mountains is ordinarily acidic. Practically all of western Chihuahua is covered by thick acidic volcanic flows. The syenites of the mountains and of western Chihuahua cut through and cover rocks of the Lower Cretaceous. The basalts in the San Carlos region are intruded through beds of Upper Eocene age. North of Lampazos and east and south of Sabinas, there are some mesas capped with lava which overlies gravel. The source of the great amount of volcanic material in the Gueydan is a mystery. The nearest known area of volcanic activity is that of the basaltic plugs north of the San Carlos. However, the ash of these beds diminishes in that direction. It seems more probable that the source of these ashes is on the east and is now covered by younger

sediments. The Front Ranges offer evidence of some sort of barrier. Whether or not they were uplifted at the same time as the Sierra Madre, is not known. Unquestionably, they were affected by the same movement. Pre-Cretaceous geography probably has influenced the formation of the Escalera-Aldamas terrace. Exactly what this influence was, there is no means of knowing. The zone of sharp folding between the Aldamas terrace and the Front Ranges is probably due to compression and possibly some lateral movement on the north, in connection with the Sierra Madre uplift. The Sierra Madre uplift is the result of a movement from the southwest, resulting in a considerable shortening of the earth's crust. A movement of this magnitude is sure to have affected the structure on the east. However, the Tamaulipas arch seems to have been the controlling factor in the folding east of the Escalera-Aldamas terrace.

OIL POSSIBILITIES

Northeastern Mexico will probably be an important oil-producing region. Development has been retarded because of the long controversy between the Mexican government and the oil companies. The political difficulties of the past seem to have been settled in such a manner that it is possible for capital to operate, and we may reasonably expect considerable activity in this region during the next few years. Mexico's new petroleum law, under which practically all the land in northeastern Mexico is held under concession, is operating to enforce exploration. Most companies holding lands in this area are entering into a more or less active exploration period. Seven wells are now being drilled in the area and several more will probably be commenced before the end of the year. In this area the same beds are deposited which are productive in southwest Texas, and in parts of the area the Lower Cretaceous is within drilling depth. The area is probably more favorable than southwest Texas because the Eocene and younger beds are more generally marine and there are many large and well defined structures.

DISCUSSION

DJEVAD EYOUB, San Antonio, Texas: In tracing the Texas formation into Mexico the geologists who have worked on both sides of the Rio Grande have been impressed by the thickening of the formation not only of the Cretaceous, but also of the Tertiary. The explanation would be interesting. Mr. Tatum finds the lower part of the Midway represented by sandstones seemingly including the sandstones of La Lajilla, N. L. These sandstones could easily be Maestrichtian, which is known to be well developed in other parts of Mexico, and the time equivalent of Velasco.

Regarding the Tamasopo limestone, C. L. Baker and others have found that the upper part includes not only the Buda, but definite Turonian fossils. In its lower part Tamasopo has very early Cretaceous fossils unknown in Texas (except in Malone) and Portlandian and Kimmeridgian from the upper Jurassic as seen at Mazapil, Zacatecas, and shown by Burckhardt and Böse.

Structurally northeastern Mexico affords interesting dissimilarity from Texas. In the part of Texas under discussion the structures are controlled by the Balcones system of faulting and the subsidence of the Mexican Gulf. In Mexico, in addition to these forces, we have the thrusts from the west which occurred at the end of the Cretaceous. Thus, the forces caused by the subsidence of the Mexican Gulf had to operate on an already existing relief caused by the earlier thrusts.

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VENEZUELAN OIL-FIELD WATERS[1]

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ABSTRACT

The identification and measurement of naphthenic acids in oil-field waters are evidence of the length of time water has been in contact with oil, and are directly proportional to the alkalinity of the water. Waters in the Maracaibo Basin can be differentiated and classified according to the sulphate-carbonate ratio. Type analyses are quoted. In the Maracaibo Basin the water types are generally conformable with geological expectations.

The principles of classification of waters and the chemical relations of oil-field waters have been exhaustively treated by many writers. In particular must be mentioned G. Sherburne Roger's "Chemical Relations of the Oil-Field Waters in San Joaquin Valley, California,"[3] a work that is invaluable to anyone who would attempt the interpretation of oil-field water analyses. It is not the writer's intention in this paper to discuss details of classification, but merely to note some facts of general interest which have been discovered in the analysis of approximately five hundred Venezuelan waters by T. Sutton-Bowman and by the writer. The original grouping was made by Bowman and has since been confirmed and amplified.

In an oil-field laboratory, waters are examined essentially for their geological interest and the actual chemistry of the water is of much less importance than the fixing of a tag, which enables the water to be recognized and placed when again encountered. Economy of time is also a factor of prime importance. In our determinations a system of volumetric analysis is used which enables the salient points of the water to be determined in the shortest time. The waters are all calculated to, and compared on, Palmer's system.

The physical characters of color, taste, and odor are noted after filtration, the presence of H_2S being confirmed if detected. The alkalin-

[1]Read before the Maracaibo Section of the Association, September 2, 1930; by title before the Association at the San Antonio meeting, March 21, 1931. Published by permission of Caribbean Petroleum Company. Manuscript received March 2, 1931.

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[3]*U. S. Geol. Survey Bull. 653* (1917).

ity is determined in presence of phenol phthalein and of methyl orange. Free CO_2, if present, is estimated by titration with an $N/50$ carbonate-free solution of sodium hydroxide. Naphthenic acids, if present in sufficient quantity, are determined as described later. SO_4 in small quantities is estimated by a visual method, the turbidity produced by the precipitated barium sulphate from a 100 cubic centimeter sample in a Nessler cylinder being compared with standard clouds in similar cylinders. Chlorides are determined in the ordinary manner by titration with standard silver nitrate solution. A measure of the alkaline earths is obtained from a determination of total hardness by the soda reagent method. This method depends on the base exchange of the calcium and magnesium salts of the strong acids with a standard solution containing sodium carbonate and hydroxide, the calcium and magnesium salts of the weak acids being precipitated on boiling.

The determination of alkalinity provides a measure of the weak acids (CO_3, HCO_3). Cl and SO_4 are direct measures of the strong acids; the hardness determination is a measure of the alkaline earths (Ca and Mg). From these determinations it is possible to calculate to, and to compare analyses on, the standard basis of Palmer's system.

It is a well known fact, of long standing, that waters associated with oil contain few or no sulphates, reduction having occurred with the production of sulphides and their subsequent replacement by carbonates with evolution of H_2S. Whether this is due entirely to chemical action or to bacteriological changes is still a controversial point, but the alteration has been recorded in a sufficient number of such waters from all parts of the world almost to form a proof. A local illustration from La Paz oil field is here noted.

	Cl*	SO_4	*Total Alkalinity*	*Total Hardness*
1. Upper waters (average 4 analyses)	6.60	0.09	0.73	0.45
2. Lower waters (average 5 analyses)	6.50	? Tr.	1.49	0.23

*In all analyses quoted Cl and SO_4 are in grams per liter. Total alkalinity, naphthenic acids, and total hardness are in grams per liter of equivalent $CaCO_3$.

In the foregoing example, if the sulphate of 1 is calculated as carbonate, the result is practically the same as 2, and there is also a diminution of the alkaline earths, as might be expected.

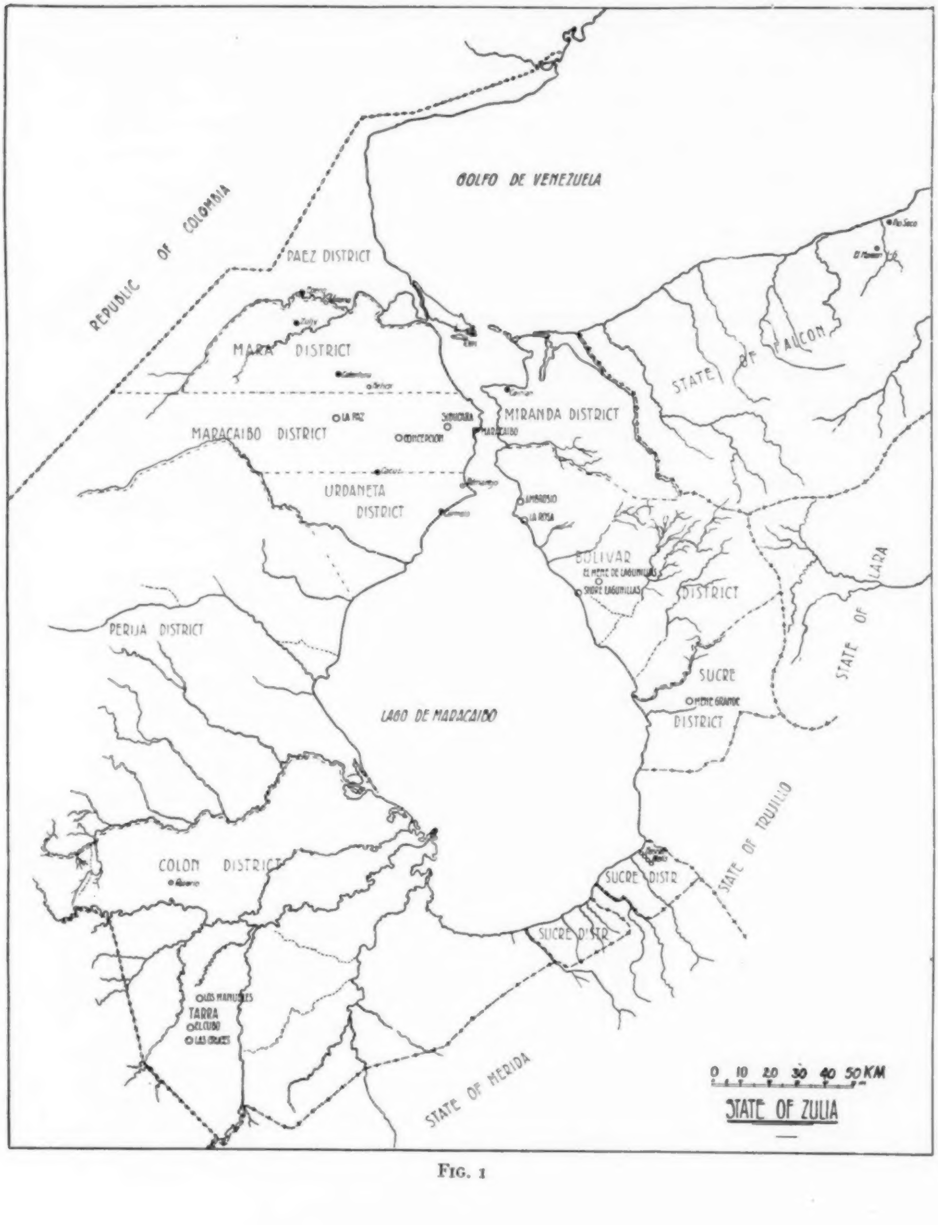
With the reduction of the sulphates occurs a collateral oxidation process which is manifested in the oil by the formation of complex hydrocarbon derivatives, the commonest of which are probably oxygen derivatives of the naphthenes, the napthenic acids.

These acids react in their turn with the alkalies in the altered water and go into solution as alkali napthenates. They can be thrown out of solution as free acid by the addition of a strong mineral acid, coming out as a milkiness or, if present in large quantities, as oily droplets. The free acid has a characteristic and very objectionable odor.

Some study has been given in the laboratory to the presence of naphthenic acids in Venezuelan oil-field waters, and a method of measurement devised. The writers measure and report the alkalinity of a water in terms of equivalent $CaCO_3$ per liter, and, as petroleum acids being present as their alkali salts make up part of this alkalinity, they also are measured as equivalent $CaCO_3$. As little work on the measurement of these acids in oil-field waters has been published, it may be of interest to report, in detail, the method used.

To a measured quantity of the original water (100 cubic centimeters is ordinarily found sufficient) in an Erlenmeyer flask, after the determination of alkalinity (or of free CO_2) in the presence of phenol phthalein, run in standardized sulphuric acid (ordinarily $N/10$) without the addition of methyl orange, which tends at this stage to obscure results. At a certain point noted as the "cloudy point," on satisfying all the carbonates and bicarbonates, the addition of a further quantity of acid commences to throw out the naphthenic acid as a white cloud with a slight bluish opalescence. The first sign of this permanent cloudiness can be readily detected if the titration is made against a black background and the eye is held almost level with the flask. The flask should be rapidly rotated from time to time to break up locally formed clouds of naphthenic acid and of evolved CO_2 bubbles. When the first appearance of the permanent cloudiness has been noticed, methyl orange indicator can be added and a fair excess of acid run in, sufficient to throw out all the petroleum acids, and to give a decided red color to the indicator. A pink color is apparent before all the naphthenic acid is precipitated, because each globule of organic acid forms a pin-point of red in the otherwise yellow liquid and a spurious red appearance is obtained before an excess of mineral acid is present. After an excess of mineral acid has been added, the naphthenic acids can be filtered off through any good thick filter paper (Postlipp 633E. is very efficient) and a back titration made on an aliquot part of the now clear filtrate with standardized ($N/50$) sodium hydroxide.

The difference between the "cloudy point" and the corrected end point obviously gives a measure of the quantity of petroleum acids present. A series of determinations of naphthenic acids by this method showed a probable error of + 18 milligrams per liter as $CaCO_3$.



GOLFO DE VENEZUELA
REPUBLIC OF COLOMBIA
PAEZ DISTRICT
MARA DISTRICT
MARACAIBO DISTRICT
LA PAZ
CONCEPCION
MARACAIBO
MIRANDA DISTRICT
URDANETA DISTRICT
AMBROSIO
LA ROSA
BOLIVAR DISTRICT
STATE OF FALCON
STATE OF LARA
PERIJA DISTRICT
LAGO DE MARACAIBO
SUCRE DISTRICT
MENE GRANDE
COLON DISTRICT
SUCRE DISTR
STATE OF TRUJILLO
LOS MANUELES
TARRA
EL CUBO
LAS CRUCES
STATE OF MERIDA
0 10 20 30 40 50 KM
STATE OF ZULIA

FIG. 1

ESTIMATION OF ALKALINITY AND NAPHTHENIC ACIDS

Alkalinity to Phenol Phthalein

100 cc. sample titrated with $N/10\ H_2SO_4$
Initial burette reading 0.2 cc.
Final burette reading 2.2 cc.

2.0 cc.

CO_3 : 2.0 × 2 × 30 mg. per liter
= 0.12 gr. per liter

Total Alkalinity and Naphthenic Acids

The same 100 cc. sample titrated with $N/10\ H_2SO_4$, "cloudy point" 39.3. Run in excess acid to 49.6 cc., filtered off naphthenic acids and back titrated 100 cc. of filtrate with $N/50\ NaOH$.

Initial reading	8.9 cc.
Final reading	20.9 cc.
$N/50\ NaOH$ used	12.0 cc.

100 cc. filtrate requires 12.0 cc. $N/50\ NaOH$

$\therefore$ 100 + (49.6 − 0.2) = 149.4 cc. require 17.9 cc. $N/50\ NaOH$

$\therefore$ corrected end point is $49.6 - \frac{17.9}{5} = 46.0$ cc.

$\therefore$ acid used = 45.8 cc.

Total alkalinity = 45.8 × 0.05
= 2.29 grs. $CaCO_3$ per liter

Naphthenic acids = 0.05 (46.0 − 39.3)
= 0.335 gr. $CaCO_3$ per liter

$$HCO_3 = 1.22 \left\{ \text{Total alkalinity} - (\text{naphthenic acids as } CaCO_3 + \text{twice } CO_3 \text{ as } CaCO_3) \right\}$$

$$= 1.22\,[2.29 - (0.335 + 0.20)]$$

$$= 2.141 \text{ grs. per liter}$$

Experiment in the laboratory with different crudes, and with different artificial waters made up to represent field types, showed that, under favorable conditions, naphthenic acids are leached from oils containing them with great rapidity. It was also found that the quantity varies directly as the carbonic acid alkalinity of the reacting water, the salts of the strong mineral acids having seemingly no effect on the leaching process.

After the crude of a field has been proved to contain naphthenic acids, the absence of these acids from a natural water of sufficient alkalinity is direct evidence that such a water has not been in contact with oil for more than a very short period of days.

For example, a highly alkaline water obtained with production in several of our South Lagunillas wells ordinarily contains merely a trace of naphthenic acids, insufficient in quantity to be measured by the foregoing method. A sample, however, bled from a production tank where it had been lying for some time, had picked up naphthenic acids to the extent of 3.07 grams as $CaCO_3$ per liter. It seems, therefore, that this water can not be present as an edge water.

Waters are broadly considered under two main types.

1. Meteoric water is ordinary rain or pluvial water which has reached its position in the strata by migration from the surface by way of outcrops or through faults and fissures.

2. Connate water used in its full sense means any water, either saline or fresh, native to the beds in which it is now found; in fact, a true "fossil" water. Of course, such water can not readily be distinguished from meteoric water and the term connate has quite improperly come to be regarded almost as a synonym for saline.

Meteoric waters, although generally of low concentration, ordinarily contain a large proportion of sulphates and carbonates, or both, in relation to the amount of chlorides.

$$\frac{(r)\,Cl}{(r)\,SO_4 + (r)\,CO_3} \text{ is low.}$$ [1]

Sea water, on the contrary, is marked by high chlorides, moderate sulphates, and practically no carbonates and

$$\frac{(r)\,Cl}{(r)\,SO_4 + (r)\,CO_3} \text{ is } 9.4.$$

Naturally, of course, change begins as soon as meteoric water starts to travel through the beds in which it occurs and in connate water as soon as it is entrapped. Nevertheless, with these distinguishing characters to start from, we have criteria for a discrimination between the origins of the waters.

A meteoric water of high sulphate class, when completely altered by contact with oil, has all the SO_4 replaced by CO_3 and/or naphthenic acids, and a high total alkalinity is the result. If the water was originally of high concentration, or has become so during migration

[1] For an explanation of the principle of reacting values symbolized by (*r*) see previously quoted paper by Rogers, p. 35, or original paper by Stabler: *Eng. News*, Vol. 60 (1908), p. 355, also chapter in *U. S. Geol. Survey Water Supply Paper 274* (1911), pp. 165-81.

from the outcrop, it is impossible for much of the alkaline earths to remain in solution as carbonates and the result is a water of low primary salinity, high primary alkalinity, and moderate or low secondary alkalinity, a high chloride salinity (of order 100 per cent) and the ratio

$$\frac{(r)\,Cl}{(r)\,SO_4 + (r)\,CO_3}$$ very low as before. Of course a similar result is to be expected with meteroic waters originally high in CO_3 and low in SO_4.

Consider a connate sea water. If the whole of the SO_4 is altered to CO_3 and allowance made for the consequent deposition of the alkaline earth carbonates, Rogers has calculated its characteristics as follows.

	Per Cent
Primary salinity	85
Secondary salinity	13
Secondary alkalinity	2

Chloride salinity is 100 per cent and

$$\frac{(r)\,Cl}{(r)\,SO_4 + (r)\,CO_3}$$ is 48.6.

It therefore becomes evident that between the 4 classes

Altered meteoric water
Unaltered meteoric water
Altered connate water
Unaltered connate water

there are considerable differences and that in nature many intermediate stages, both in degree of alteration and in proportions of admixture of the classes, can exist. In the light of these principles, seven main types of water have been recognized in the Maracaibo Basin; these, with their characteristics, are tabulated (Table I). It is noticeable that no pure connate type waters have been found; but the Eocene waters of La Rosa, Colon, and the Maracaibo district approach this type. Table II shows examples.

It is of interest to notice that the water of Maracaibo Lake is very close in type to average ocean water, although only about $1/24$ of its concentration. On approaching Toas Island, where the tide and influx of sea water make themselves felt, the concentration rises, and on the north side of the island opposite the village of El Toro the concentration rises to about $1/3$ that of average ocean water.

TABLE I

CLASSIFICATION OF MARACAIBO BASIN WATERS

	Total Reaction Value Milligrams H. Per Liter	*Chloride Salinity (Per Cent)*	$\frac{(r)\ CO_3}{(r)\ SO_4}$	$\frac{(r)\ Cl}{(r)\ CO_3 + (r)\ SO_4}$	*Primary Salinity (Per Cent)*	*Secondary Salinity (Per Cent)*	*Primary Alkalinity (Per Cent)*	*Secondary Alkalinity (Per Cent)*
1. Normal surface and ground waters..	Ordinarily very low; may rise very high	Ordinarily <80	Ordinarily high; may be <1 in waters of high concentration	Varies considerably; ordinarily <1.0	Very variable	May occur	Very variable	Some very high; ordinarily >25
2. Mixed connate and meteoric waters (the former predominating) showing some or no modification by oil......	High 158-1,102	76-92.5	Ordinarily <1	>2.0	78-95	May occur	0-20	0-10
3. Mixed connate and meteroric waters (the latter predominating) showing some or no modification by oil.......	Low 13.5-47	89.5-94	High, >10	>0.3 <1.0	30-50	Nil	40-48	4-30
4. Meteoric water, partly modified by oil..............................	Moderate 28-67	76-94.5	May be very high; always >1	<0.6	10-46	Nil	50-83	4-12
5. Mixed connate and meteoric waters (the former predominating) completely altered by oil.....................	High 122-601	>99	∞	>2	65.5-95	May occur	0-31.5	1-5
6. Mixed connate and meteoric waters (the latter predominating) completely altered by oil.....................	Moderate 53-191	100	∞	>0.2 <1.5	21-52.5	Nil	42.5-67	3.5-15
7. Meteoric water showing complete alteration by oil.....................	Low-Moderate 12-165	100	∞	<0.2	2-16	Nil	72-93	3-26

TABLE II

EXAMPLES OF EOCENE WATERS APPROACHING CONNATE TYPE

	Chlorides	*Sulphates*	*Total Alkalinity*	*Naphthenic Acids*	*Total Hardness*	*Total Reaction Value in Milligrams Hydrogen Per Liter*	*Chloride Salinity (Per Cent)*	*Primary Salinity (Per Cent)*	*Secondary Salinity (Per Cent)*	*Primary Alkalinity (Per Cent)*	*Secondary Alkalinity (Per Cent)*
R-96 micaceous sst. waters of La Rosa VOC, av. 18 analyses......	5.12	Trace	0.31	Nil to trace	0.31	308	100	94	Nil	2	4
3d coal horizon of Tarra CDC...............	10.10	0.04	0.75	? Tr.	0.50	601	99.5	95	Nil	1.5	3.5
Netick 1, Orinoco Oil Co.	5.81	0.02	0.72	Nil	0.14	358	100	92	Nil	6.5	1.5
Calentura 1, Orinoco Oil Co..................	12.9	0.2	0.11	? Tr.	1.95	740	98.5	89.5	10	Nil	0.5
Epeng. 1, Atlantic Refining Co.	20.2	0.01	0.60	Nil	0.44	1,161	100	98	Nil	0.5	1.5
Caiman 1, Cal. Pet. Co..................	17.4	2.42	0.04	Nil	5.06	1,102	91	82	18	Nil	Nil

	Cl	SO_3	T. Alk.	Naph. Acids	T. Hard	T. R. V.	Ch. Sal.	P.S.	S.S.	P. A.	S. A.
Average lake near Maracaibo ...	0.80	0.11	0.05	Nil	0.29	53.5	92.5	78.5	18	Nil	3.5
Lake water north of Toas.	6.50	0.90	0.07	Nil	1.80	409	91	82.5	16.5	Nil	1

CLASSIFICATION OF MARACAIBO BASIN WATERS

TYPE 1. NORMAL SURFACE AND GROUND WATERS

Concentration is ordinarily low. Exceptions are a very shallow water from a blow-out in LS-59 (Lagunillas) and a similar blow-out water from R-229-234 (La Rosa). Very saline waters of high concentration were found during pitting work at La Paz and seem to be due to a concentration of salts of the saline connate water near the surface by evaporation.

To this class belong all the river, swamp, *caño*, and most spring waters. It includes the shallow waters of El Cubo, shore Lagunillas, and the water of the Quaternary sandstone south of Maracaibo and in the town itself. This water forms the main source of the town supply and is widely exploited by shallow hand-dug wells. Pockets of this Quaternary sandstone resting on older Concepcion series (Eocene) contain the sweet water, and many wells carried too far into the sandstone capping have struck the connate salt water of the older beds.

	Chloride	SO_4	Total Alkalinity	Naphthene Acids	Total Hardness	Total Reaction Value	Chloride Salinity (Per Cent)	Primary Salinity (Per Cent)	Secondary Salinity (Per Cent)	Primary Alkalinity (Per Cent)	Secondary Alkalinity (Per Cent)
El Cubo shallow water, av. 3 analyses	0.03	0.03	0.27	Nil	0.32	13.6	60	20.5	Nil	14	65.5
Quaternary sst. of Maracaibo, av. 29 analyses ..	0.12	0.01	0.07	Nil	0.07	9.8	94	71	26	Nil	3
Rio San Pedro, Mene Grande..............	0.02	0.02	0.01	Nil	0.06	2.4	65	6.5	75.5	Nil	18
LS-59 blow-out..........	2.81	2.23	0.48	Nil	0.48	272	63	92.5	Nil	.5	7
La Paz, Pit 268..........	18.53	16.68	0.30	Nil	8.06	1751	60	81.5	18	Nil	.5
SR. 4, Rosario..........	0.01	Nil	0.04	Nil	0.01	2	100	24	Nil	57	19

TYPE 2. MIXTURES OF CONNATE AND METEORIC WATERS, THE FORMER PREDOMINATING, SHOWING SOME (OR NO) ALTERATION BY OIL

La Paz, upper salt water, 4 analyses	6.60	0.09	0.73	?	0.45	439	91	93.5	Nil	2.5	4
Sibucara 1, at 1,300 feet	6.60	0.74	0.51	?	0.17	426	92.5	95	Nil	3	2
La Concepcion, upper salt water, 4 analyses	8.33	3.53	0.78	?	0.38	648	76	95	Nil	2.5	2.5
Zuljy 1, A. R. C.	3.15	0.15	1.30	Nil	0.11	236	97	78	Nil	20	2

All these are of Eocene age.

TYPE 3. MIXTURES OF CONNATE AND METEORIC WATERS, THE LATTER PREDOMINATING, SHOWING SOME (OR NO) ALTERATION BY OIL

This small group includes:

Shallow gas sand, La Rosa	0.12	0.01	0.17	Nil	0.03	13.7	94	50	Nil	41	9
Mirador sandstone of Cubo, 8 analyses	0.07	Tr.	0.24	Nil	0.10	13.5	89.5	30	Nil	40	30
Cacuz water well	0.45	0.12	0.21	Nil	0.40	39	83.5	59	19	Nil	22

TYPE 4. METEORIC WATER PARTLY ALTERED BY OIL

1st coal horizon of Cubo	0.07	0.03	1.16	? Tr.	0.09	51.5	76	10	Nil	83	7
Cubo sand of Cubo	0.13	0.01	1.13	?	0.16	53	94.5	15	Nil	73	12
Palmarejo 1, Omnium Oil Co.	0.44	0.15	0.91	Nil	0.07	67	80	46	Nil	50	4
Boscan 4, Sun Oil Co.	0.04	Tr.	0.58	Nil	0.02	25	92	9	Nil	87	4

The last two are of Miocene age.

TYPE 5. MIXTURE OF CONNATE AND METEORIC WATERS, THE FORMER PREDOMINATING, SHOWING COMPLETE ALTERATION BY OIL

La Paz deeper waters, 5 analyses	6.50	?Tr.	1.49	Tr.	0.23	424	100	86	Nil	12	2
La Concepcion, 3rd level	5.72	Nil	3.21	F.tr.	0.25	451	100	72	Nil	26	2
El Mene de Lagunillas deep water	2.24	Tr.	0.77	?	0.12	158	100	81	Nil	16	3
Amana 1, VGOC bailed 3,342 feet	3.41	Nil	0.86	Nil	0.11	227	100	85	Nil	13	2

See also analyses of Epeng. 1, R. 96 type, 3d coal horizon, and of Netick, already quoted. All these are of Eocene age.

TYPE 6. MIXTURE OF CONNATE AND METEORIC WATERS, THE LATTER PREDOMINATING, SHOWING COMPLETE ALTERATION BY OIL

Tars and water of La Rosa, 6 analyses	0.69	Nil	2.03	Max. 0.61	0.08	120	100	32.5	Nil	63.5	4
Upper sand of Ambrosio, 6 analyses	1.23	0.02	2.56	0.18	0.42	173	99	40	Nil	50	10
Misoa-Trujillo sandstone of Mene Grande	1.11	?Tr.	1.47	Tr.	0.17	121	100	51.5	Nil	42.5	6

These, with the exception of the Mene Grande water, which is Eocene, are of post-Oligocene age.

TYPE 7. METEORIC WATERS COMPLETELY ALTERED BY OIL

Alkaline waters of Lagunillas, 23 analyses	0.22	0.01	3.36	+	0.35	147	96.5	9	Nil	82	9

+The naphthenic acid content varies ordinarily from only a faint trace to 3.07 grs. as $CaCO_3$ per liter in a sample drawn from a tank, see p. 897 This water almost conforms to Rogers' reversed type, where a meteroic water originally high in sulphates gives rise by alteration to a water sulphate-free and high in carbonates.

Upper tar sand type of La Rosa, 2 analyses	0.15	Nil	2.03	0.6	Max. 0.06	89	100	9	Nil	88	3
Carmelo 1, VGOC, 3 analyses	0.27	Nil	0.99	Nil	0.07	55	100	28	Nil	67	5
Maracaibo series waters of Mene Grande:											
Group 1	0.08	?Tr.	0.26	Nil	0.03	11.5	100	10	Nil	80	10
Group 2	0.07	Nil	0.50	V.F. tr.	0.06	23.5	100	16	Nil	74	10
Group 3	0.04	Nil	0.89	F.tr.	0.18	38	100	6	Nil	75	19

All of these are of post-Oligocene age.

From broad geological consideration of the Maracaibo Basin sediments, it is found that formations ranging from Cretaceous to Oligocene (the latter not found within the basin proper) were deposited in water of marine type. The Icotea beds of the Bolivar district from the top Oligocene to the basal Miocene are problematical, but because of scarcity of faunal life and curious lithology (white kaolin-like clays and sandy clays) might almost be considered of terrestrial origin, varying at the top to shallow-water conditions, as shown by the presence of coal and of amber. Following this comes the definitely marine Miocene, in which saline connate water would be expected, and above this again the Maracaibo series (younger Tertiary), probably the result of deltaic conditions. Therefore, saline or at least brackish waters may be expected in the whole of the pre-Miocene column, and in only a small part of the post-Oligocene are definitely saline connate waters to be expected.

This is shown to be true, in the main, by preceding analyses. No definitely saline purely connate waters are found above the Eocene. In La Rosa, from the upper Oligocene to the lower Miocene, the waters are of mixed type, and even where noticeable, the connate nature has been subordinated by meteoric dilution. The greatest discordance is found in the Colon district, where, in the 3rd coal horizon, there is a strongly saline connate water, succeeded upward by a fresh meteoric water of low concentration in the Mirador sandstone (included in the Eocene column). This may be explained partly by the proximity of the outcrop in a region of heavy rainfall, but under similar circumstances in Mene Grande, although diluted, the Eocene waters of the Misoa-Trujillo sandstone still show more traces of their original connate nature than the Mirador water.

Outside the Maracaibo Basin proper, in the Mamon wells of the Coro Petroleum Company, and the Rio Seco wells of The Creole Petroleum Company, under different geological conditions, a saline connate water has been found in beds of middle and upper Miocene age.

DISCUSSION

W. E. WINN, Dallas, Texas (written discussion received March 4, 1931): Some of the data furnished by Mr. Smith, those concerning the naphthenic acids, are very interesting. G. Sherburne Rogers, in a paper on "Geochemical Relations of the Oil, Gas, and Water of the Sunset-Midway Field," mentioned naphthenic acids, but Mr. Smith's are the first definite data we have seen on the subject. We have noticed a cloudiness in a very few waters, but in each it could be attributed either to hydrogen sulphide, or to the soaps in oil emulsion-treating compounds. However, the paraffine-base oils with which we ordinarily deal probably do not contain enough of the naphthenic acids, if any, to show in such a test.

I should like to comment also concerning the absence of sulphates in oil-field waters. Mr. Smith states in his paper that "It is a well known fact of long standing that waters associated with oil contain few or no sulphates, reduction having occurred with the production of sulphides and their subsequent replacement by carbonates with evolution of H_2S." Mr. Smith's experience in Venezuela, and Mr. Rogers' experience in the San Joaquin Valley substantiate this statement. The statement, however, must be limited to particular fields, and even to particular strata, for we have analyses from many fields which show high contents of sulphates in the waters associated with the oil. In some localities sulphates are present in the water associated with the oil in one horizon and are not present in the water associated with the oil from another horizon.

In further comment, this theory of the replacement of sulphates and formation of hydrogen sulphide intimates that waters containing hydrogen sulphide are low in sulphates. Our results show, however, that as a general rule oil-field waters containing hydrogen sulphide are high in sulphates, though

the presence of sulphates is not everywhere an indication of the presence of hydrogen sulphide. Practically all of the waters produced with the sour oils of West Texas are high in sulphates (several thousand parts per million) and hydrogen sulphide, as are likewise the waters produced with the oil from the Edwards limestone at Luling. The waters from the cap-rock production in the Spindletop field are high in sulphates and hydrogen sulphide, but the waters with the deep production on the flanks of the dome contain no sulphates. A water produced with the oil from the Sun-Richmond Petroleum Company's El Mamon 1-A in Venezuela tested 233 parts per million of sulphates at a depth of 3,471 feet. A long list of individual analyses in our files shows the same results of high sulphates and hydrogen sulphide.

R. H. FASH, Fort Worth, Texas (written discussion received March 9, 1931): In this paper, J. E. Smith calls attention to the importance of considering the chemical composition of the horizon from which a water comes. Primary alkaline water is formed by the interchange of bases of the water and zeolites occurring in sands.[1] While a primary alkaline water can be found in a limestone or dolomite, it is not to be supposed that the water acquired its primary alkalinity in the limestone or dolomite unless this contained a large amount of sand. Primary alkaline waters probably do not travel any great distance through a limestone or dolomite without being changed to a secondary saline water. Naphthenic acids are soluble in water because of the primary alkalinity of the water. Therefore, naphthenic acids are not found in waters occurring in limestones and dolomites, or in secondary saline waters.

The presence or absence of sulphates in waters associated with oil is also dependent upon the chemical composition of the horizon from which they are produced. Sulphates occur in waters associated with oil produced from limestone and dolomitic formations. They are always accompanied by hydrogen sulphide. An investigation to determine the cause of this condition would probably yield information of value to geologists. In waters associated with oil produced from sands, sulphates have been eliminated or reduced to a very small percentage.

PAUL D. TORREY, Bradford, Pennsylvania (written discussion received March 14, 1931): This paper treats very thoroughly some of the changes in the chemical composition of the solute, in comparison with present sea water, of a class of oil-field waters that greatly differ in character from the Appalachian type of oil-field waters with which the writer is most familiar. The discussion of the absence of sulphates in oil-field waters is very interesting and the conclusions established by Mr. Smith seem to be most logical for the region treated in his paper. In the light of my experience in the eastern fields it seems evident that no fixed principles regarding the origin of oil-field waters can be established that may be applied under all conditions. Mr. Smith's explanations fully account for the present character of the Venezuela waters, but it is obvious that they might not be so successfully applied to areas producing oil that is essentially composed of saturated hydrocarbons. I would suggest, for the purpose of uniformity, that the analyses of oil-field waters be expressed

[1] B. Coleman Renick, "Base Exchange in Ground Water by Silicates," *U. S. Geol. Survey Water-Supply Paper 520-D* (1925).

in parts per million by weight rather than in other form. Although the conversion to standard terms as established by the United States Geological Survey and the American Public Health Association is very simple, it seems desirable that this standard be universally adopted for Association papers.

L. C. CASE, Tulsa, Oklahoma (written discussion received May 6, 1931): Mr. Smith's paper is a worthy contribution to the study of oil-field hydrology and presents an outstanding example of the value of using certain characteristics in local interpretation. However, I question the correctness of a point or two. The statement, "it is a well known fact of long standing that waters associated with oil contain few or no sulphates, reduction having occurred with the production of sulphides and their subsequent replacement by carbonates with evolution of H_2S. . . . the alteration has been recorded in a sufficient number of such waters from all parts of the world almost to form a proof," does not apply in the Mid-Continent region. The waters of the "Wilcox" sand and Arbuckle limestone, which are Ordovician in age, are surely much older than the Venezuelan oil-field waters. That these waters have been associated with oil for long periods of time is beyond question. However, the sulphate content of some of these waters is high, the maximum being 10 per cent of the total solids in some places. It seems true that the formation of carbonates is attended by the evolution of H_2S. However, water in the Arbuckle limestone of southern Kansas, which has approximately the concentration of sea water and has a relatively high bicarbonate and H_2S content, also contains as much as 2.5 grams per liter of sulphate. It may be argued that the process of reduction is here going on but is not yet completed. It seems that no meteoric water can have entered this formation since Mississippian time. Therefore, the reaction must be proceeding at a much slower rate than in some Tertiary waters cited in the literature in which the reduction is complete. The author assumes that if sulphate is not present in a bottom water, the water has been altered by oil. There are many examples of bottom waters in the pools of the Mid-Continent area which have only traces of sulphate and carbonates and no H_2S. These are essentially solutions of sodium, calcium, and magnesium chlorides which range as high as 200 grams per liter in total solids. If carbonates and H_2S are always formed in the process of reduction of sulphates, these waters have never been subjected to such a process. Either sulphates were not present at the time of entrapment of water in the sediments or they were precipitated out as insoluble sulphates by contact with other solutions

FUNCTION OF CARRIER BEDS IN LONG-DISTANCE MIGRATION OF OIL[1]

JOHN L. RICH[2]
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ABSTRACT

Many facts of distribution of oil indicate that it is capable of migrating for considerable distances. The great decrease in the viscosity and surface tension of oil when gases are dissolved in it and at the higher temperatures found at considerable depth render oil much more mobile at depth than it is at the surface. The same is true of water.

It is not necessary to think of oil as migrating mainly in the beds which now form its reservoirs. The reservoir beds should be considered, rather, as beds into which the oil once entered and became trapped so that it has since been unable to escape.

Migration may be mainly through especially porous beds or "carrier beds" such as coarse sheet sands or cavernous limestones. From these the oil works its way upward at every opportunity into higher beds where it may be trapped, or in which it may continue its migration.

Anticlines and other structural disturbances, by causing fissures through which fluids can escape upward from the carrier beds, become centers toward which rock fluids, including oil, move from all directions and thereby become localizers of oil accumulation from wide areas. The fissures cause fluid movement toward the anticlines and their structure provides effective traps for the oil.

Oil may enter lenticular sands from carrier beds below wherever fissuring has occurred, and especially where they cross fissured anticlines, but, having entered them, it finds escape more difficult.

In the later physiographic history of a region the carrier beds may be flushed by circulating water while the beds above, and especially lenticular sands, may be unaffected.

INTRODUCTION

Many features of the distribution of oil find much more ready explanation if one is free to invoke extensive and in some regions long-distance migration.

One of the strongest arguments for extensive migration is the fact that the accumulation of oil is closely controlled by structural situations which would have favored the segregation of oil from water. The enormous accumulations of oil and gas in such structurally high areas as the Sabine uplift of Louisiana, the Bend arch of Texas, and the Seminole uplift and the Oklahoma City field of Oklahoma are almost inconceiv-

[1]Expanded from paper read before the Association at the San Francisco meeting, March 21, 1928. Manuscript received, April 1, 1931.

[2]Consulting geologist.

able unless there has been extensive migration to those areas from a considerable territory around them.

Another argument for extensive migration is that in many places the oil does not seem to have been derived from local sources and fails to show any definite relation to local source rocks.

The fact, now well established, that oil has been flushed out of rocks in areas having strong artesian circulation implies that oil must travel freely in water that is in vigorous circulation. If it is flushed out of one place it must be accumulated somewhere else.

In spite of the evidences pointing to the theory that extensive and in places long-distance migration of oil has occurred, many geologists (perhaps the majority of those in the Mid-Continent) are still inclined to believe that oil can not have migrated very far and that the source of most of it is close to where it is found.

Reasons for this belief seem to be: (1) the difficulty of conceiving of long-distance migration through the pores of the fine-grained reservoir rocks which now constitute the oil reservoirs; (2) the widespread occurrence of oil in lenticular sands; and (3) failure to credit the important function of circulating water in oil migration and accumulation.

The purpose of the writer is to outline a possible mechanism for long-distance migration which seems reasonable and competent and which obviates many of the difficulties which have hitherto interfered with the acceptance of the idea that such migration could have occurred. The mechanism outlined provides competent channels for migration; means for cross-bed migration; for accumulation in beds other than that in which the migration occurred; an effective means of concentrating oil and gas in areas structurally favorable; and, finally, it offers an explanation of the modifications in the character and distribution of the oil which follow changes in the physiographic aspects of a region.

In order that the theory here proposed may be presented as clearly and concisely as possible, only limited reference is made to illustrations from the field. Most of the facts on which the theory is based are well known. In a paper now in preparation the writer applies the theory to the specific problem of the origin, migration, and accumulation of oil in the Oklahoma-Kansas section of the Mid-Continent fields. The present purpose will be achieved if the mechanism on which the theory rests is presented clearly enough so that its application to specific conditions anywhere can be made by the reader, who will, of course, give due consideration to possible deviations from the ideal scheme here outlined. The effective test of the theory is its ability to explain what is found in the field.

INCREASED MOBILITY OF OIL CAUSED BY DISSOLVED GAS AND HIGHER TEMPERATURES AT DEPTH

Within recent years experimental data have been secured which have a very significant bearing on the problem of the migration of oil.

Studies by Beecher and Parkhurst[1] have shown that the viscosity and surface tension of oil are greatly decreased by dissolved gas. To quote:

> At a pressure of 500 pounds, and a temperature of 70° F., it was found that a natural gas such as is associated with the oil would reduce the viscosity about 50 per cent when a given crude oil was saturated with the gas..... Pressures of 1,800 pounds may exist at depths around 4,100 feet and at present a large amount of oil is being produced from much greater depths. Under such pressures, sufficient gas might dissolve in the oil to make the viscosity almost equal to that of kerosene. (Pp. 51-52.)

Quoting further:

> The surface tension of crude oil is reduced by dissolved gas. The results of experiments with two different crude oils saturated with gas at pressures from 400 to 500 pounds indicate a reduction of approximately 20 per cent in the surface tension of the oils.

The experiments cited show that the amount of gas dissolved in oil varies directly with the pressure. It would therefore vary directly with the depth of burial were it not that temperatures increase with depth and Beecher and Parkhurst show that, for a given pressure, less gas is dissolved at the higher temperatures. The effect of this, however, is relatively slight, amounting, according to calculations made from Beecher and Parkhurst's curves, to the difference between a 53 per cent reduction in viscosity for a pressure of 500 pounds at constant temperature and a 50 per cent reduction for a pressure of 500 pounds caused by burial to 1,150 feet with its accompanying temperature increase of about 11° C. The net effect of this lessened solubility of gas at the higher temperatures is to reduce slightly, but not significantly, the decrease in viscosity resulting from pressure due to burial.

More recent studies[2] have shown that the amount of natural gas actually dissolved in the crude oil as it exists in the earth is much greater than that which Beecher and Parkhurst succeeded in dissolving in dead

[1] C. E. Beecher and I. P. Parkhurst, "Effect of Dissolved Gas upon the Viscosity and Surface Tension of Crude Oil," *Petrol. Development and Technology in 1926* (Petroleum Division, A. I. M. E.), pp. 51-69.

[2] Report of paper by Ben E. Lindsly, "Preliminary Report on an Investigation of the Bureau of Mines Regarding the Solubility of Natural Gas in Crude Oil," *Min. and Met.*, Vol. 12 (March, 1931), pp. 165-66.

oil under laboratory conditions—275 cubic feet per barrel of oil when reduced from 300 pounds pressure as compared with about 70 cubic feet absorbed under laboratory conditions. From a pressure of 1,672 pounds per square inch 800 cubic feet of gas per barrel of oil was liberated.

Not only are the viscosity and surface tension of oil greatly reduced by the gases which dissolve in it at high pressures, but they are still further reduced by the higher temperatures which accompany the greater depths and pressures.

Higher temperatures also greatly decrease the viscosity of water (Fig. 1), so that at a temperature of 90° C., which would be reached at a

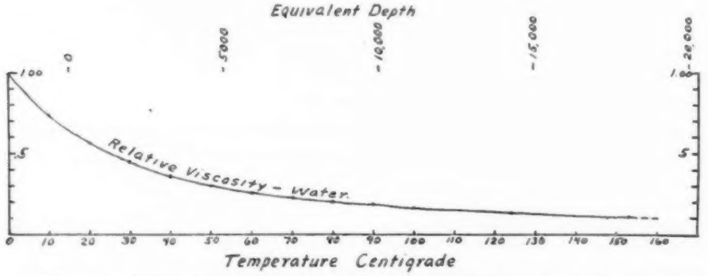

FIG. 1.—Relative viscosity of water at different temperatures and their equivalent depths of burial. Temperature gradient 3° C. per 100 meters. Viscosities from *Handbook of Chemistry and Physics*, Charles D. Hodgman and Norbert A. Lange, 13th ed., pp. 759-60. Depths in feet.

depth of about 10,000 feet, water would flow through the rocks three times as readily as at surface temperatures. At 20,000 feet it would flow about six times as readily.

The surface tension of water is reduced as the temperature rises, and at a greater rate than that of oil where dissolved gas is not a factor (Fig. 2). This suggested that, at depth, the surface tensions of oil and water might approach each other so that they would migrate more nearly as one fluid, but calculations made from Beecher and Parkhurst's data and from data from Figure 2 indicate that the effect of dissolved gas more than counterbalances this tendency, so that at depth the surface tensions are farther apart than at the surface.

From the foregoing discussion it is obvious that the lowering of the viscosity of oil by dissolved gas, the lowering of the viscosity of both oil and water by the higher temperatures to which they are subjected at considerable depths, and the lowering of the surface tension of oil by

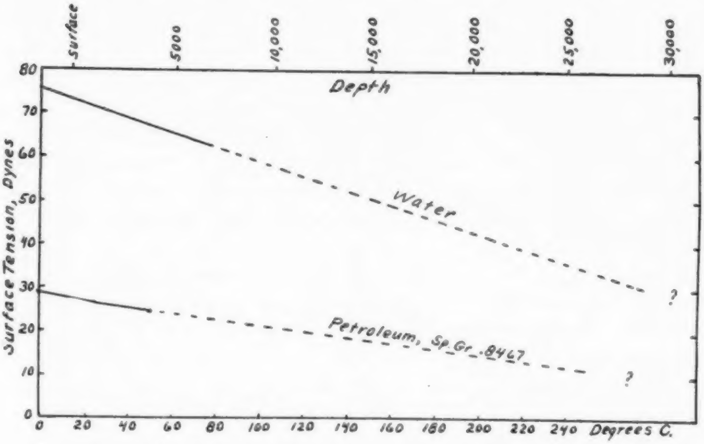

FIG. 2.—Relation between temperature and surface tension of water and crude oil at temperatures corresponding with different depths of burial. The effects of dissolved gases are not indicated. Depths in feet.

dissolved gas and higher temperatures, all tend to make the rock fluids much more mobile at depth than at the surface. In other words, in considering the possibility of the long-distance migration of oil, we are dealing with a very different and much more mobile fluid than the crude oil with which we are familiar. Both the oil and the water are able to move through rocks much more readily at the comparatively great depths at which most of the migration presumably took place than they are at the surface. That fact should be borne in mind constantly in connection with the following discussion.

CARRIER BEDS

The physical relations of viscosity and surface tension outlined in the preceding paragraphs greatly decrease the difficulty of imagining extensive long-distance migration of oil—migration for tens or even for hundreds of miles. What of the channels of migration? Must we think of the oil as necessarily migrating through the fine-pored reservoir rocks in which it is now found? By no means. We should, rather, think of the oil as migrating as an integral constituent of the rock fluids, along with water, through any and all possible channels open to it, and mainly through those which offer the greatest freedom of movement, and from

these escaping, as opportunity may offer, into the finer-pored reservoir rocks in which it is now found.

In order to simplify reference to such especially pervious channels of possible migration, the writer has coined the term *carrier bed*.

Carrier beds may be of several kinds. Relatively coarse sheet sands of great porosity, such as the St. Peter ("Wilcox") sand of the Mid-Continent; the Dakota group of sands of the Rocky Mountain district; or the Tensleep sand, constitute one of the most important types of carrier bed.

Another effective type of carrier bed, or perhaps, rather, carrier zone, is the weathered and dissolved surface of widespread limestone formations buried beneath an unconformity. Examples are the top of the Arbuckle limestone ("Siliceous lime") of Oklahoma and Kansas; the top of the "Mississippi lime" of the same region; and the top of the Trenton limestone on the Cincinnati arch of Ohio and Indiana. Belts of shattering in limestone could also serve as effective carriers.

ENTRANCE OF OIL INTO CARRIER BEDS

In considering long-distance migration of oil, we may begin with the oil already in the carrier bed. How it came there is not primarily the theme of the present discussion, but, lest the argument might seem to fail at that point, some of the possibilities may be mentioned.

Oil may have been squeezed into the carrier bed from adjacent source rocks as the latter became compacted. Such has been suggested as the source of much of the oil in the Dakota sandstone. It may also find its way into the carrier bed from near-by source rocks through local fissures or shatter belts. In areas of mountain building and extensive dynamic metamorphism, many avenues of entry into the carrier beds may be opened by faulting, fissuring, and shattering of the rocks.

In this connection attention is called to the dikes or veins of grahamite and similar hydrocarbons which are found at several places in the Ouachita region of Oklahoma and Arkansas[1] and also in West Virginia.[2] These veins, like the better-known mineral veins, cut across the bedding and range in width from mere stringers to as much as 25 feet. Fissures such as these would give perfectly free opportunity for cross-bed migration into the carrier beds or out of them.

[1] Joseph A. Taff, "Grahamite Deposits of Southeastern Oklahoma," *U. S. Geol. Survey Bull. 380* (1909), pp. 286-97.

[2] I. C. White, "Origin of Grahamite," *Bull. Geol. Soc. Amer.*, Vol. 10 (1899), pp. 277-84.

MOVEMENT OF OIL IN CARRIER BEDS

After oil has entered the carrier beds, its migration through them would be controlled by the nature of the porosity of the carrier and by the nature of the forces causing movement. In carriers formed by the solution of limestone at buried land surfaces, the porosity might have the nature of a connected series of solution channels which would offer opportunities for movement almost as free as that through pipe lines. In such a carrier the only limit to the distance to which oil might migrate seems to be the extent of the carrier horizon. In such a carrier, also, the forces of capillarity would not be effective. Therefore, the buoyancy of oil with respect to water should be adequate to cause up-dip migration even in the absence of water movement.

Sheet sandstone carrier beds offer easy paths for extensive migration which, however, would be subject to capillary influence except that, on account of the relative brittleness of sandstones, intersecting joints might be a considerable factor in the migration.

The driving force causing movement through such sands would doubtless vary with conditions. Water squeezed out of surrounding rocks by their compaction might possibly set up a considerable circulation through the carrier bed out of the deeper parts of deep sedimentary basins, but the writer doubts if such a circulation would extend very far toward the outcrop before being dissipated by upward leakage through the roof. Even this upward leakage, however, would be a factor in oil migration as outlined in subsequent paragraphs.

In areas undergoing regional metamorphism, newly generated gas may be an effective driving agent, forcing fluids, carrying oil along with them, ahead of it out of the area where the gas is being generated, and also carrying oil along with it in the form of films on the bubbles of gas, as outlined by Mills.[1] Another effective cause for migration through such a carrier bed is artesian pressure.

During movement of the rock fluids through a carrier bed due to any of the driving agencies already mentioned, we must think of the oil as always tending to work its way upward—toward the roof of the carrier bed, toward the higher structural situations, and out of the carrier upward into other beds wherever fissures or any similar pathways occur. On closed structures oil would be trapped and held in the carrier unless

[1] R. Van A. Mills, "Natural Gas as a Factor in Oil Migration and Accumulation in the Vicinity of Faults," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 1 (January-February, 1923), pp. 14-24.

it had opportunity to escape upward or unless the circulation were strong enough to flush it out.

Whether oil having the low viscosity and surface tension which, as previously indicated, would prevail at depths of 5,000 feet or more would be able to migrate up-dip through a coarse sandstone carrier bed such as the St. Peter ("Wilcox") sand on account of buoyancy alone, without assistance from circulating water, is one of the problems yet to be solved. It is certain, however, that its greater mobility at depth would make such movement of oil more probable than it is under surface conditions of viscosity and surface tension.

In a deep synclinal basin, artesian pressure, the squeezing of water into the carrier from adjacent beds as they became compacted, and the pressure of newly generated gas not only tend to cause lateral movement in the sands, as already outlined, but they also tend to cause the contents of a porous carrier bed such as we are considering to escape *upward* from the carrier at every available opportunity.

Slichter[1] has called attention to the fact that in an artesian basin a large part of the water which enters the aquifer at the outcrop may escape upward by leakage through the roof.

Evidence of extensive upward leakage is furnished by the fact that the water which must be squeezed out of the sediments as they are compacted does not seem to find its way to the surface at the outcrops. On the contrary, on coastal plains such as that bordering the eastern United States and the Gulf of Mexico, we find artesian fresh water below sea-level, as at Charleston, South Carolina, and Galveston, Texas. This indicates that meteoric water from the outcrops is working its way out under the sea. Such a movement means that, somewhere, upward leakage must occur and must be greater in amount than the water supplied by the compaction of the sediments. Otherwise the fresh waters could not penetrate below sea-level under the influence of their artesian head.

ANTICLINES AS LOCALIZERS OF UPWARD MOVEMENT OF ROCK FLUIDS

If we grant the premise that the fluids in the carrier beds are generally seeking every available opportunity to escape upward on account of artesian pressure, water of compaction, or gas pressure, we are led to extremely interesting conclusions which place anticlines, salt domes, and fault structures in a new light as localizers of oil accumulation.

[1]C. S. Slichter, "The Motions of Underground Waters," *U. S. Geol. Survey Water Supply Paper 67* (1902), p. 56.

In brief, an anticline, salt dome, or other structural disturbance probably involves more or less shattering, jointing, or possibly faulting of the rocks.[1] It thus tends to open a channel for the upward escape of rock fluids, including oil and gas along with water, from the carrier bed below. As soon as such a channel has been opened, the fluids in the carrier bed tend to converge toward it from all directions[2] and to move upward to the surface, or, more probably, into higher porous beds in which it may spread out as opportunity offers.

Oil and gas carried upward with the water will be separated from it and accumulated in the higher beds if their structural arrangement is such as to make a trap. If not, they will continue their movement until a suitable trap is encountered. Fractured anticlines, salt domes, and similar structures would form ideal traps in the upper beds. Simple faults might or might not form traps.

The consequence of fluid movement in the carrier bed toward the structure which furnished a channel for its upward escape would give such structures far greater "gathering areas" from which to draw their oil and gas than would be accounted for by the size of the structures themselves. For example, a salt dome might cause a doming of the strata in an area having a diameter of only 2 or 3 miles. Under the theory of up-dip migration due to buoyancy this would constitute a very small "gathering area," but under the concept here advanced it might become a center toward which water and oil would converge from many miles around. If its closure were adequate it would screen out and trap all of the oil brought to it.[3]

In working its way upward from the carrier bed along fissures on an anticline or other disturbed structure, the water and oil might or might not reach the surface. In many places they would not, but would spread laterally in one porous zone, or several, which might themselves become secondary carrier beds with respect to which a similar process might be repeated on other structures.

[1]This statement scarcely requires the support of references, but in a region like the Mid-Continent, where the folds are comparatively gentle, evidences of such shattering are likely to be overlooked and the fact of their having occurred may be questioned. Gish and Carr (Wesley G. Gish and Raymond M. Carr, "Garber Field, Garfield County, Oklahoma," *Structure of Typical American Oil Fields*, Vol. 1, pp. 176-91) have given convincing evidence of the presence of considerable shattering in the Garber field. Mills (*op. cit.*) gives many references to shattering and faulting on oil-producing anticlines, and a search through the literature would reveal many more.

[2]*Cf.* Mills, *op. cit.*

[3]Such a conception is offered in rebuttal of Gardner's argument for strictly local origin of the salt-dome oil. (James H. Gardner, *Oil and Gas Journal*, March 3, 1927, pp. 154, 156, 157).

In this connection it is important to bear in mind that in many fields, particularly in the older rocks, the migration of the oil undoubtedly occurred when the rocks were much more deeply buried than now, so that what is now the surface may then have been thousands of feet underground. The greater the depth of burial the greater the mobility of the oil and the more readily it would find its way upward out of the carrier bed through small fissures or shatter belts. Also, the greater the depth of burial the greater the opportunity for lateral dissipation of the rock fluids in beds above the carrier without reaching the surface, and for secondary migration in these higher beds.

Such a mechanism offers a means by which oil could readily gain access to lenticular sands where it might undergo further secondary migration as the nature of the sand bodies might permit.

After oil had found its way up out of the carrier bed into overlying beds and had accumulated there, its connection with the carrier bed might, in many places, be lost through the closing of the channels by which it had entered. Such sealing might result from the gradual closing of fissures which had remained open for a considerable time after their formation, or by their filling with vein materials. It might also result from the tendency of oil and gas deposits to seal themselves in by deposition of salts in the surrounding sands.[1]

The upward escape of oil and gas from a carrier bed where fissures or shatter belts permit would occur even if none of the three factors mentioned at the beginning of this section were operative, and the water were in hydrostatic equilibrium and had no tendency to work its way upward. Both oil and gas, on account of their buoyancy, would tend to accumulate on anticlinal or other favorable structures from which they would work their way upward wherever possible, irrespective of the lack of upward movement of the water.

The upward escape of gas in this way would set up a flow toward the structure, as Mills[2] has indicated, and the gas would carry oil along with it and ahead of it as he has shown. The convergence of oil and gas movement toward the structure would be more effective, however, if the water were under pressure so that it also would work its way upward at every opportunity.

[1] R. Van A. Mills, "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U. S. Geol. Survey Bull. 693* (1919); notice especially pages 76, 89-95.

[2] *Op. cit., Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 1 (January-February, 1923), pp. 14-24.

POSSIBLE LATER FLUSHING OF THE CARRIER BED

Physiographic changes in a region in which widespread migration of oil in a carrier bed and its accumulation in favorable structures in that bed or above it had occurred, could readily change the function of the carrier bed from that of a channel of oil migration and accumulation to one of vigorous artesian water flow.

The first effect of such a change would be to re-energize the migration and segregation into favorable traps of the oil remaining in the carrier; the later effect would be to flush the carrier bed and to sweep away accumulations already made, unless they were protected by strong closure, faults, or other effective barriers. An accompanying effect would be to change the gravity of the oil remaining in the carrier, rendering it heavier.

Such flushing of the carrier bed would, in general, have comparatively little effect, and in many places none, on accumulations of oil in higher beds, to which it had once migrated from the carrier bed, because: (1) they would lie outside the path of free circulation through the carrier; (2) small fissures leading to them would be less effective than formerly because of greater viscosity of the water following the shallower depth and lower temperatures associated with the new physiographic cycle; (3) to some extent the fissures would have been closed and the oil and gas would have cemented themselves in.

The net result of all these factors would be that the carrier bed would be flushed, but the accumulations of oil in higher beds would be comparatively little affected.

One phase of this result would be that the oil remaining in the carrier bed would be rendered heavy by the oxidizing effect of the circulating water, although that in the beds above would be unaffected or much less affected and would retain more nearly its original gravity.

Another result of changes in water circulation in the later history of a region might be to flush oil out of two or more of several sands on a structure while leaving oil undisturbed in other sands between them which did not happen to be channels of free water movement.

FUNCTION OF LENTICULAR SANDS AS BARRIERS TO FLUSHING

In the later physiographic stages of a region, the lenticular sands begin to function in another way, namely, as protectors against flushing.

Under the conditions of low viscosity and low surface tension which would prevail during the period of migration when the sands were deeply buried, it would be much easier for oil to gain access to the lenticular

sands than to be removed from the same sands during the later physiographic cycle when the oil had become somewhat heavier, its viscosity greater, and the channels leading to it partly sealed. We should expect, therefore, to find one of the most important functions of lenticular sands to be that of forming obstacles to flushing. Oil would still remain in them long after it had all been flushed out of the sheet sands of the region. An excellent illustration of this function is in eastern Oklahoma and eastern Kansas, where the porous carrier beds below have been almost completely flushed but the oil still remains in the lenticular sands.

DISTANCE OF MIGRATION DEPENDENT ON LOCAL CONDITIONS

In the preceding pages a mechanism has been outlined by which long-distance migration of oil could readily be accomplished, and by which many of the features of the distribution of oil in several sands of a pool and in lenticular sands can be explained. Obviously, however, not all oil has migrated great distances. In some fields it may still be found close to its place of origin, in others it may have migrated possibly hundreds of miles. Whether the oil in any pool was formed close to where it is found or has migrated to the pool from a distance depends on the location of the pool with respect to source rocks, to agencies which have caused the generation of oil from them, and to possible channels of migration.

Recognition of the possibility of long-distance migration frees the searcher from the necessity of finding a local source for the oil in a particular field and gives a broader basis from which to study all of the evidences bearing on the problems not only of the origin of the oil, but also of its peculiarities of distribution and its modifications on its journey to its present reservoir.

DISCUSSION

JAMES H. GARDNER, Tulsa, Oklahoma (written discussion received, June 18, 1931): Mr. Rich has written a very clear analysis of an old theory and enlarged on it to include factors that tend to facilitate migration of petroleum and natural gas both laterally and vertically. Just as someone coined the term "source rocks" to fit the theory of origin, so he coins the term "carrier beds" to fit the theory of migration and accumulation. One is consistent with the other, but the coinage of a term and its usage often prove a sign-post which points out the wrong highway along the journey to the land of truth and confines research to a particular field of thought, whereas research should be left unrestricted.

The question is not so much confined to whether or not liquid and gaseous hydrocarbons *can* travel long distances but rather to the field evidence to indicate whether or not these accumulations *have* so traveled. Probably every

student of the subject will admit that accumulations of oil and gas in commercial quantities have been moved to some extent. They have done some accumulating and have adjusted themselves to water pressure or points of least resistance; but whether accumulated from local areas or from long-distance migration, laterally through "carrier beds" from distant "source rocks" is quite another question.

Toward the close of Mr. Rich's paper, he uses the following sentence, "Whether the oil in a given pool was formed close to where it is found or has migrated to the pool from a distance depends on the location of the pool with respect to source rocks, to agencies which have caused the generation of oil from them, and to possible channels of migration." Here he ties the whole theory to at least one important stake, namely, "source rocks." If "source rocks" are near, the accumulation is local possibly; if "source rocks" are not near, the migration was from a far distance where "source rocks" are. The logic is sufficiently consistent, but the premise from which the conclusion is drawn is itself a theory, namely, the "source-rock" theory. Where are the source rocks and what are they?

The argument from field evidence in favor of local accumulation (or local movement) as contrasted to regional accumulation (or regional movement) is one that requires a paper of considerable length and can not well be presented briefly or in part only. Mr. Rich states that he has in preparation an article in which he applies his theory to the specific problems of origin, migration, and accumulation in Oklahoma and Kansas. This should be an interesting paper and in it must be involved matters pertaining to the historical record of local structures with their present accumulations and the question of the relative time when accumulations occurred, were lost by erosion, followed by later accumulations, et cetera. Considerable important rebuttal argument can be made when these specific points are presented and various other questions will arise so long as the origin of oil is not known.

The writer believes that the problem is not so simple as outlined by Mr. Rich and that it will remain unsolved until we get at the solution of the problem of the origin of oil and natural gas. For example, if oil and natural gas be the result of chemical reactions, catalysis, et cetera, or other undiscovered media, where would the term "source rocks" apply? Or if these hydrocarbons be from an inorganic source and have risen from below the sedimentary rocks, notice the effect which that fact might have on the question of lateral migration through carrier beds, as contrasted to vertical accumulation through fractures in local areas above the point of release where even sand-lenses would absorb a supply. There is evidence to show that joints and fractures die out in coming upward; igneous dikes so die out, and possibly in a similar manner do veins or dikes of grahamite. The writer believes that we should proceed very slowly on the basis of reasoning from the theory of "source rocks" lest we come to accept them as a fact before such is demonstrated. But on the subject of migration, field evidence is strictly to the point and let us have more analysis of the circumstances with respect to that problem. It is this side of the argument that has led many geologists to abandon the theory of long-distance migration; even though the long-distance theory seems exceptionally logical at some places, it fails woefully at others, which indicates that there is something wrong with

it. There are many places where oil should be found and is not found on that theory, and on the contrary too much oil is found where it should not be found on the basis of that theory. But this brings up a long discussion which can not be covered here. Perhaps it will suffice to state that there are many unconformities of overlap around the perimeters of oil-producing basins which form ideal trapping grounds for long, meandering pools along the strike-lines directly up-dip from rich local pools on local structures, but such pools are absent. Well known sands also pinch out up-dip as excellent traps which fail to have accumulation so that for ten failures to find these oil pools where they should be there is one situation where accumulation seems to fit the theory. There should be hundreds of pools like the East Texas pool, provided the oil and gas have traveled upward for long distances out of the basins. Under these circumstances, instead of the exception proving the rule, the exception is the rule. This leads the writer to believe, among many other things, that we have not yet found the answer.

DEEP SAND DEVELOPMENT IN TIOGA COUNTY, PENNSYLVANIA[1]

JACK GADDESS[2]
Port Allegany, Pennsylvania

ABSTRACT

The Tioga County gas field, in the northern part of Tioga County, in Farmington Township, was discovered on September 10, 1930, by the Allegany Gas Company, producing company of the North Penn Gas Company, in its Palmer No. 1, at a total depth of 4,010 feet. Production of 22,000,000 cubic feet of gas of 1,050 B. T. U. and 0.58 specific gravity and with no trace of sulphur was found in the Oriskany sand of Lower Devonian age.

The field is on a dome on the Sabinsville anticline with an indicated closure of more than 200 feet. Twelve other wells are being drilled on this and adjacent anticlines. This development is strictly "wildcat" as the discovery well is 40 miles from any commercial production.

Maps, cross sections, and tables show the subsurface structure, generalized well log, and the development on February 20, 1931.

INTRODUCTION

The Tioga County gas field is in the eastern part of Farmington Township, in northern Tioga County, Pennsylvania (Fig. 1). In its present stage of development it occupies an area 7 miles long and 3 miles wide. Fifty miles west is the older, shallow Potter gas field and 40 miles north is the more recently discovered Dundee gas field in northern Steuben County, New York.

The field now covers approximately 7,000 acres. This area may be increased to 10,000 acres when the limits are defined by present drilling.

In this preliminary paper are presented the history of the development of the field and general geological facts as known, February 20, 1931. A detailed treatise can be given more appropriately when additional data are secured and they are no longer considered confidential.

Although the data given here are drawn principally from the files of the Allegany Gas Company, much information has been obtained from geologists of other companies interested in the field who have aided through free exchange of thought and data.

[1]Read before the Association at the San Antonio meeting, March 20, 1931. Manuscript received, February 28, 1931.

[2]Geologist and engineer, North Penn Gas Company.

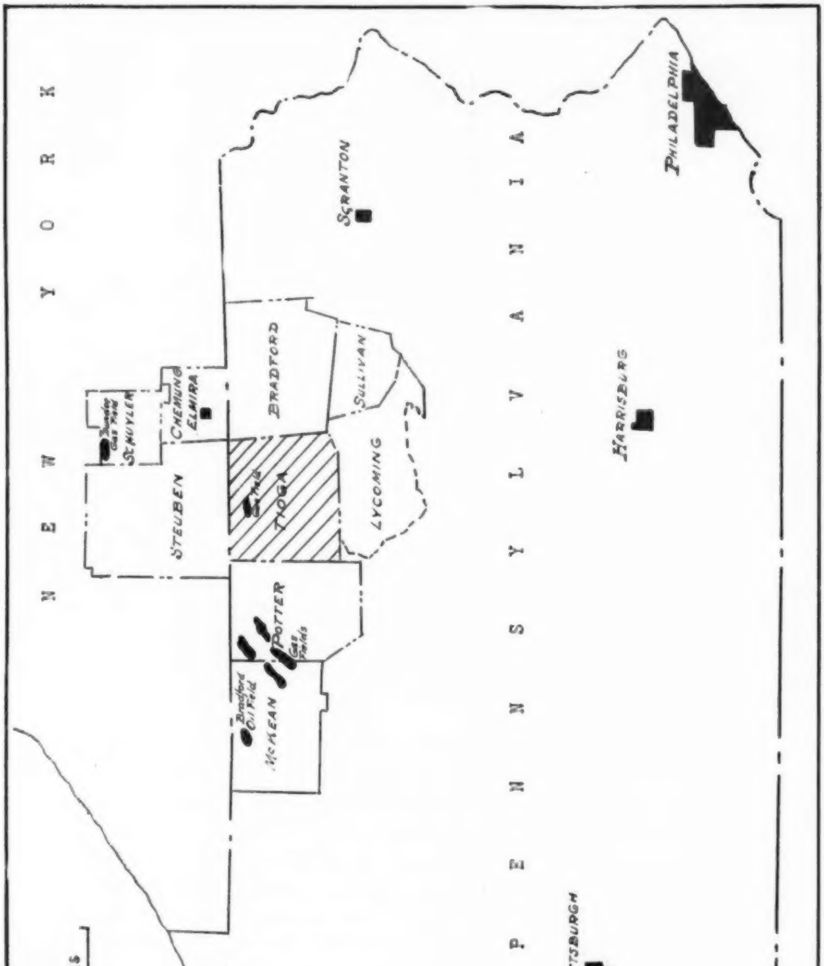

FIG. 1.—Key map showing location of Tioga County gas field.

Events leading to the development of the Tioga County field began in the spring of 1930 with reconnaissance work by the writer and W. F. Craig, Jr., in the employ of the Allegany Gas Company. In the course of this work, the topography, drainage, and reverse dips along the axis of the Sabinsville anticline in northern Tioga County suggested closed structure. This area was detailed and the work indicated three separate "highs" on the axis, tentatively named (1) Sabinsville structure in Clymer Township, (2) Farmington structure in Farmington and Lawrence townships, and (3) Jackson structure in Lawrence and Jackson townships, all in Tioga County, Pennsylvania. Of these three "highs," the Farmington structure had the most pronounced closure with the most evident quaquaversal dips. A closure of several hundred feet was indicated. Recommendations were made and by June, 1930, a solid block of approximately 7,000 acres had been leased by the company on the Farmington structure. The Sabinsville structure had indicated closure, but lower structurally than the Farmington structure. A block of 3,500 acres was acquired on this structure.

The test well was located on the Farmington structure on the L. B. Palmer farm in northeastern Farmington Township. Drilling was commenced in early July and on September 10, 1930, a gas "pay" was found in the top of the Oriskany sand at a depth of 4,010 feet with an initial flow of 300,000 cubic feet. Drilling was continued to 4,012 feet and the flow increased to 1,000,000 cubic feet per day. At this time, the pipe in the hole consisted entirely of 750 feet of 8¼-inch as a water string and an 8-inch hole was drilled to 4,012 feet. The tools were pulled with the intention of running a string of 6⅝-inch pipe to the bottom before drilling in, but 2 hours later the well blew in with an open flow of 10,000,000 cubic feet. Three miles of 6-inch line was laid to the company's 12-inch main line and the well was turned into the pipe-line system. Three days later the well was opened prior to running 6⅝-inch pipe and the flow was gauged as 22,000,000 cubic feet. The string was landed on the bottom and cemented with 700 sacks of cement. The cement on the inside of the 6⅝-inch pipe was re-drilled and the bit went out of cement into sand at 4,016 feet, thus placing the bottom of the hole 6 feet in the Oriskany sand.

Table I is a record of the formations drilled.

The well was not drilled through the sand. The gas "pay" is composed of fairly regular, medium to coarse, heavily frosted, rounded quartz grains, cemented with siliceous material and having a porosity of approximately 9 per cent.

TABLE I

Depth in Feet	*Formation*
260	Slates, light gray
267	Sand, light gray
275	Slates, light gray
280	Sand, gray
380	Slates, dark gray
390	Sand, gray
457	Shale, dark gray
465	Sand, dark gray
695	Sand, shells, light gray
865	Slate, gray
950	Shale, dark gray, gas
967	Shells, gray
975	Sand, gray
1,005	Shale, dark gray
1,012	Sand, dark gray
1,050	Slate, shells, dark gray
1,065	Slate, light gray
1,078	Sand, slate, light gray
1,145	Slate, dark gray
1,160	Sand, dark gray, gas
1,285	Slate, light gray
1,297	Shale, black
1,370	Slate, dark gray
1,384	Sand, light gray
1,560	Slate, shells, shale, black (0-1,560 CHEMUNG)
1,592	Sand, gray
1,615	Sand, broken, gray
1,622	Sand, gray
1,690	Sand, broken, dark gray
1,696	Shale, dark gray
1,705	Shells, gray
1,716	Slate, gray
1,735	Sand, broken, gray
1,741	Sand, gray
1,756	Sand, broken, gray
1,830	Slate and shells, gray
1,842	Shells, dark gray
1,890	Slate and shells, gray
1,960	Slate and shells, gray
1,995	Slate and shells, gray
2,030	Slate, gray
2,050	Shale, light gray
2,070	Sand, gray
2,090	Slate and shells, gray
2,097	Sand, gray
2,125	Slate and shells, gray
2,270	Slate, black
2,295	Sand, gray
2,312	Shells, gray
2,330	Slate, gray
2,360	Sand, broken, gray
2,371	Sand, gray
2,392	Shale, gray
2,405	Sand, dark gray
2,434	Shale, gray
2,445	Sand, gray
2,470	Slate, shells, light gray
2,595	Sand, gray (1,561-2,595 PORTAGE)
2,605	Lime, gray
2,664	Shale, dark gray, pyrite (2,596-2,664 GENESEE)
2,667	Slate and shells, gray
2,690	Slate, dark gray
2,765	Shale, dark gray
2,777	Slate, shells, dark gray
3,015	Shale, gray and black
3,100	Lime, sandy, gray
3,120	Shell, lime, dark gray
3,180	Shale, dark gray
3,500	Shale, dark gray (2,665-3,500 HAMILTON)
3,557	Lime, gray
3,930	Shale, dark gray, pyrite
3,940	Shale, black, pyrite
3,950	Shale, limy, black, pyrite
3,970	Shale, calcareous
3,980	Shale, black (3,501-3,980 MARCELLUS)
3,987	Lime, slaty, black
3,995	Lime, sandy, cherty, black (3,981-3,995 ONONDAGA)
4,016	Sand, light gray to white, hard. Gas "pay" (3,996-4,016 ORISKANY)

TOPOGRAPHY

The Tioga County field is in the plateau area of the Allegheny Mountains. The relief is about 700 feet, ranging from 1,100 feet above sea-level on Cowanesque River on the north edge of the field to 1,800 feet on the tops of the hills. The hills are rolling and are farmed.

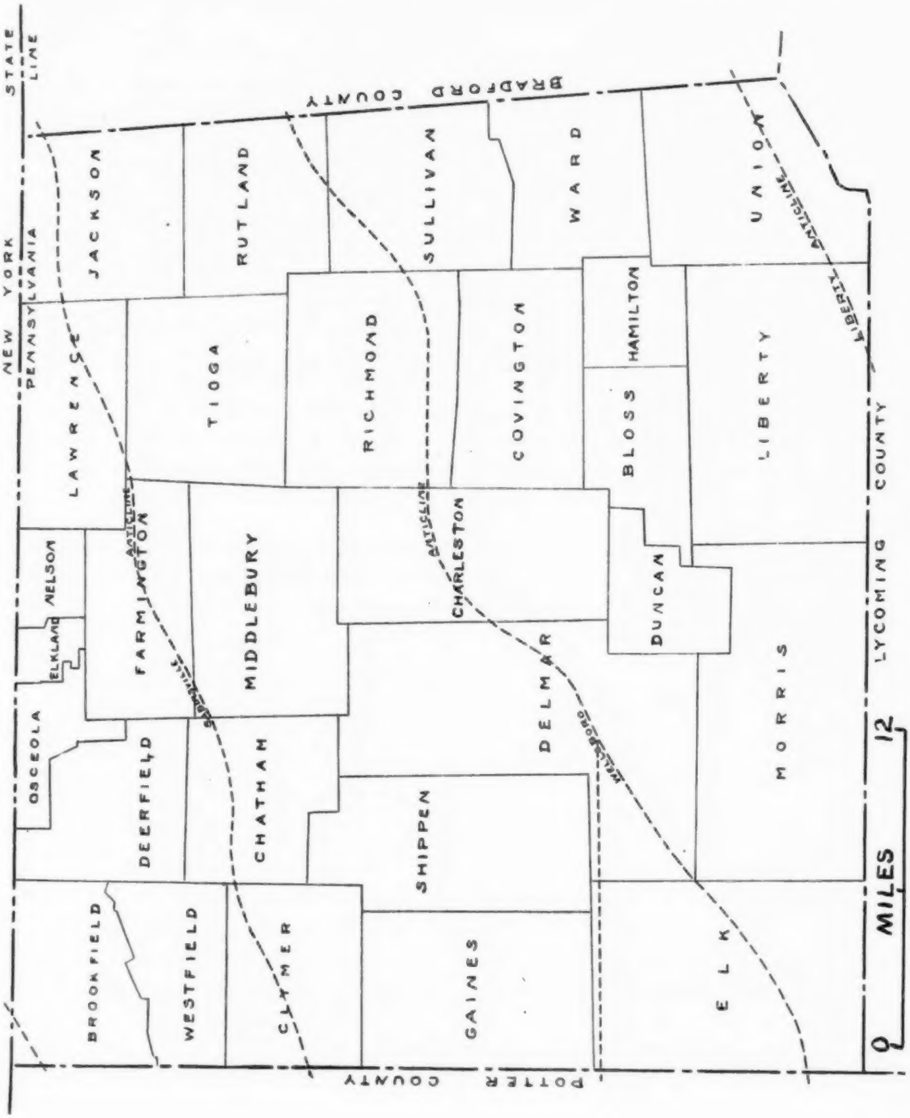

FIG. 2.—Map showing surface structural features, Tioga County, Pennsylvania.

SURFACE FORMATIONS

The surface formations are all of the Chemung formation of Upper Devonian age along the axis of the anticline and well down the flanks. The synclines have brought down the red shales and sandstones of the Cattaraugus, formation. The Chemung formation is composed of gray-to-buff thin-bedded sandstones, shales, and limestones. This formation does not contain any definite key horizon for surface structure mapping, but the thin-bedded strata afford distinct contacts for determining dips.

SUBSURFACE FORMATIONS

Devonian formations constitute the subsurface section from the surface to the Oriskany horizon. They include the Chemung formation, composed of alternating gray slates, limestones, and sandstones; the Portage formation, composed of thin-bedded slates and shells and sandstones; the black and gray shale beds of the Genesee and Hamilton formations, with several limestone horizons; the black, bituminous shales of the Marcellus formation; and the black, cherty Onondaga limestone. A tentative division of the strata into formations is shown on the preceding log.

The contact of the Chemung and Portage and the contact of Hamilton and Marcellus are not definite, but will be determined after a more detailed examination of drill cuttings has been made.

SURFACE STRUCTURE

The surface structure of the producing area is an elongate dome 7 miles long and 1½ miles wide within a closing contour 300 feet below the crest. The axis of the structure is "dog-legged," the strike on the western side being N. 65° E. and changing to N. 83° E. on the eastern side of the crest. The dips on the southeast flank range from 8° to 14° and on the northwest flank from 4° to 7°. The surface structure map (Fig. 3) shows the steep dip on the south flank.

SUBSURFACE STRUCTURE

The dips on the formations increase with their depth. Final development may show 500 feet of closure on the Oriskany sand. The major axis of the structure shifts northward so that at a depth of 4,000 feet the highest point is approximately 2,000 feet from the highest point on the surface structure, giving the axial plane an inclination of 27°.

The steep south dip in the subsurface beds is terminated in the Onondaga limestone and deeper formations by an underthrust fault.

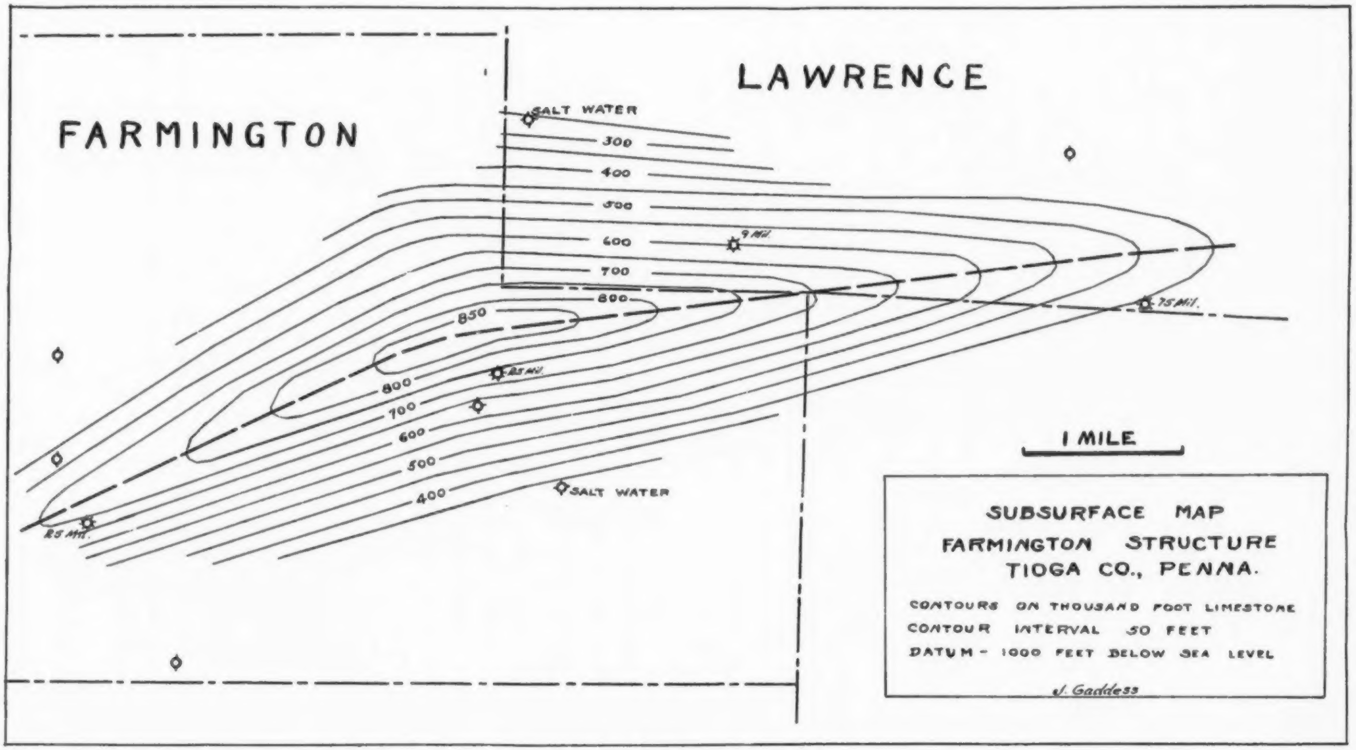
LAWRENCE
FARMINGTON
SALT WATER
300
400
500
600
700
800
850
800
700
600
500
400
SALT WATER
9 Mil.
7.5 Mil.
8.5 Mil.
8.5 Mil.
1 MILE
SUBSURFACE MAP
FARMINGTON STRUCTURE
TIOGA CO., PENNA.
CONTOURS ON THOUSAND FOOT LIMESTONE
CONTOUR INTERVAL 50 FEET
DATUM - 1000 FEET BELOW SEA LEVEL
J. Gaddess

FIG. 3

The strike of the fault can not be determined from data at hand. The fault is established by the Allegany Gas Company's No. 1143 and No. 1144. In all wells drilled in the field to date, the formations have been very regular down to the Onondaga limestone. Excellent markers occur at the contact of the sandy beds of the Portage and the black shales of the Genesee, at a limestone approximately 1,000 feet above the Oriskany sand, and at a limestone drilled about 500 feet above the Oriskany sand. Well 1143 drilled the 1,000-foot limestone at 3,015 feet and well 1144, which is 1,200 feet south, drilled the same limestone at 3,040 feet. Well 1143 drilled the Oriskany at 4,010 feet and well 1144 drilled the Oriskany at 4,350 feet or 388 feet lower structurally. The fault seemingly does not extend above the Onondaga limestone. In the People's Natural Gas Company's Howe No. 1, approximately 3,500 feet southeast of well 1144, and J. E. Trainer's Bostwick No. 1, approximately 8,000 feet north of well 1143, conditions correspond with those found in the aforementioned wells. The throw of the fault is estimated from the preceding figures to be at least 350 feet. Knowledge of the extent of the fault will necessarily await further drilling. It is of primary interest in connection with the field, as it seems to be a controlling factor in the formation of the fold and the accumulation of gas.

DEVELOPMENT

Development has been rapid in the field. The completion of the discovery well on such a large anticline in the surface beds has created great interest among the natural gas companies in the eastern states. It ushers in an era of deeper drilling in northern Pennsylvania to a horizon which has been productive in remarkably few wells in the Appalachian fields. Possible production of natural gas in such volumes in territory within relatively short distances of the metropolitan areas on the Atlantic seaboard has created much activity among major companies. The completion of 16 wells with initial flows of 5,000,000 cubic feet, or more, from the same producing horizon near Dundee, New York, undoubtedly affected the rate of development in Tioga County.

The larger companies have mapped the surface geology in all of Tioga County and for 50 miles in all directions. More than 1,000,000 acres of land has been leased in this area and this leasing activity has extended into New York state to meet that activity created by the Dundee field, 40 miles farther north.

Drilling operations have been rushed because of drilling clauses and high delay rentals in leases. Table II is a report on operations as of February 20, 1930.

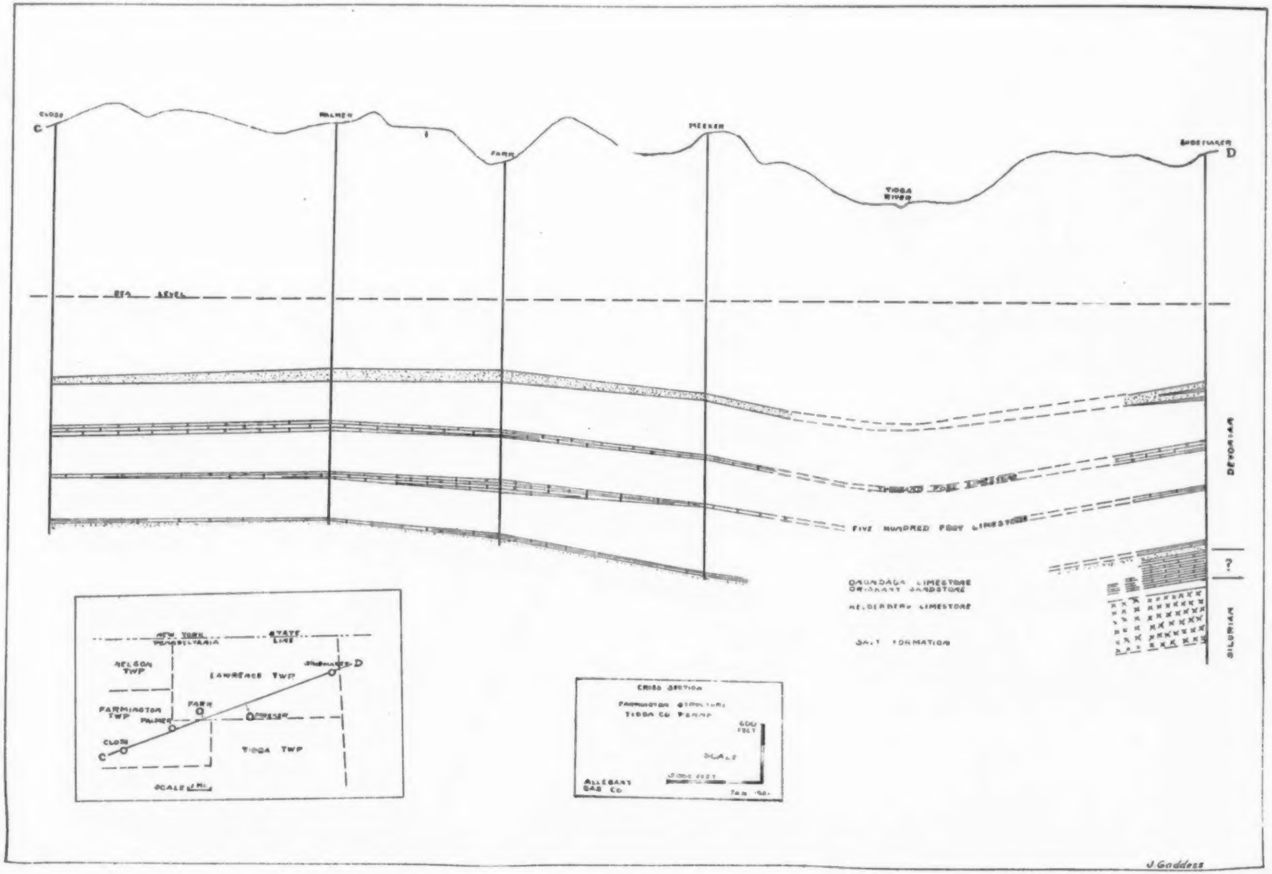

FIG. 4.—Southwest-northeast cross section, Farmington structure, Tioga County, Pennsylvania.

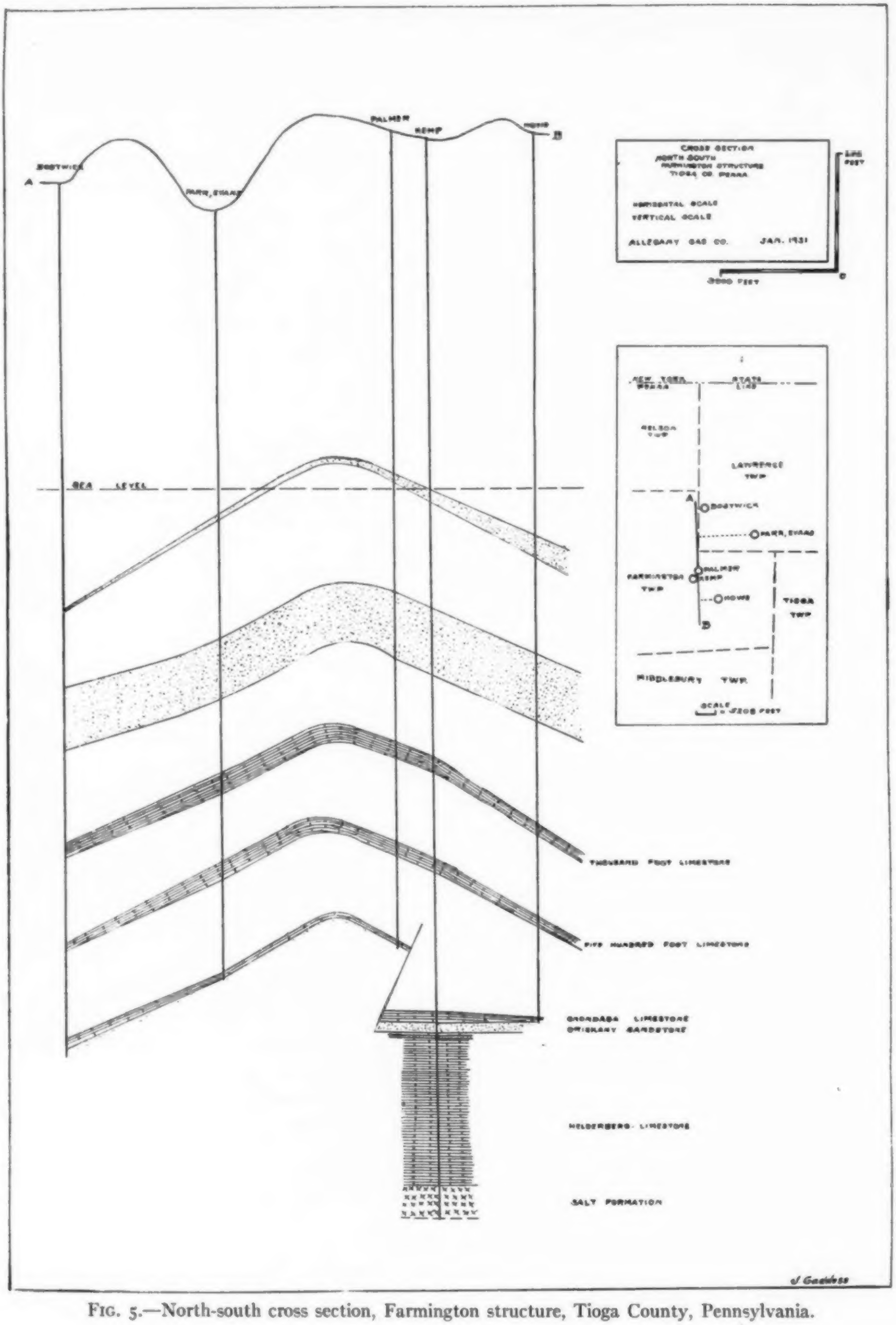

FIG. 5.—North-south cross section, Farmington structure, Tioga County, Pennsylvania.

TABLE II

Company	Farm	Township	County	State	Depth in Feet	Remarks
Allegany Gas Company	Palmer 1	Farmington	Tioga	Pennsylvania	4,016	22,000,000 cubic feet
Allegany Gas Company	Kemp 1	Farmington	Tioga	Pennsylvania	4,600	Dry in Oriskany
Allegany Gas Company	Palmer 2	Farmington	Tioga	Pennsylvania	....	Location
Allegany Gas Company	Colegrove	Lawrence	Tioga	Pennsylvania	....	Location
Allegany Gas Company	Lavey 1	Richmond	Tioga	Pennsylvania	....	Location
People's Natural Gas Company	Howe 1	Farmington	Tioga	Pennsylvania	4,391	Salt water in Oriskany
People's Natural Gas Company	Shoemaker	Lawrence	Tioga	Pennsylvania	....	Dry in Oriskany
People's Natural Gas Company	Ackley	Clymer	Tioga	Pennsylvania	....	Drilling in Oriskany
People's Natural Gas Company	Taft 1	Woodhull	Steuben	New York	4,100	Dry in Oriskany
People's Natural Gas Company	Boom 1	Lawrence	Tioga	Pennsylvania	....	Drilling
People's Natural Gas Company	Hoyt 1	Farmington	Tioga	Pennsylvania	....	Location
Penn Ohio Oil Company	Close 1	Farmington	Tioga	Pennsylvania	4,017	25,800,000 cubic feet
Penn Ohio Oil Company	Price 1	Farmington	Tioga	Pennsylvania	3,000	Drilling
J. C. Trees Company	Farr 1	Lawrence	Tioga	Pennsylvania	3,780	9,500,000 cubic feet
J. C. Trees Company	Farr 2	Lawrence	Tioga	Pennsylvania	....	Location
P. Benedum Company	Perkin 1	Addison	Steuben	New York	4,472	Dry in Oriskany
P. Benedum Company	Perkin 2	Addison	Steuben	New York	....	Drilling
J. E. Trainer	Bostwick 1	Lawrence	Tioga	Pennsylvania	4,244	Salt water in Oriskany
Penn United Gas Company	Meeker	Tioga	Tioga	Pennsylvania	4,197	66,000,000 cubic feet
Hope Engineering Company	Birch 1	Brookfield	Tioga	Pennsylvania	4,260	Cementing cave
J. W. Leonard	Harrison	Lawrence	Tioga	Pennsylvania	1,300	Drilling
Fischer *et al.*	Adams	Charleston	Tioga	Pennsylvania	....	Drilling
E. A. Williams	Husted	Woodhull	Steuben	New York	1,001	500,000 cubic feet shallow sand

On February 24, 1931, there were eight completed wells on the Farmington structure, four of which were producing gas wells with a total open flow of approximately 120,000,000 cubic feet per day. Two other wells were drilled into salt water, one on the north flank and one on the south flank. The remaining two completed wells were dry, one showing 60 feet of Oriskany sand and the other, 54 feet of sand. Both of these wells are being drilled deeper. Drilling in two wells at present is above the Oriskany. Rigs are being installed on four locations and there are 12 other locations on the structure which will be drilled at once.

Future development will be determined primarily by market outlets. At present, the North Penn Gas Company, parent company of the Allegany Gas Company, operates the only natural-gas pipeline system in northern Pennsylvania east of the Bradford field. This system extends from Oil City, Pennsylvania, to Elmira, New York. The Columbia Gas and Electric Corporation operates a pipeline system extending across southern New York state approximately 15 miles north of the Tioga gas field. If the wells now being drilled extend the producing area, major pipeline extensions will unquestionably be made by the larger companies.

DISCUSSION

K. C. HEALD, Pittsburgh, Pennsylvania (written discussion): Mr. Gaddess' paper is a welcome addition to published data on the stratigraphy and structure of the area in northern Pennsylvania that has recently come into the limelight. He has furnished just the sort of brief sketch of geologic conditions that is greatly needed when a new district suddenly becomes of interest.

One or two points which he has mentioned should, I believe, be further elaborated, inasmuch as he shows conditions in his illustration which are not explained in his text. To be specific—his illustration, which shows a cross section in a north-south direction across the Farmington structure, seems to call for a period of deformation following Onondaga time but preceding the time when the 500-foot limestone was deposited. If we accept this illustration, we must postulate an unconformity somewhere in the interval between the Onondaga limestone and the 500-foot limestone, with either strong erosion or, as an alternative, the development of sharp topography controlled by faulting and with this topography subsequently buried before the 500-foot limestone was deposited.

So far as I can learn, there is no support for the idea that an unconformity occurred at this position, or that during Marcellus time there was a period of sharp deformation. It seems probable, therefore, that some explanation other than that shown by Mr. Gaddess in this cross section will be required to explain the conditions.

The relative positions of the key beds and the comparative thicknesses of the formational units can be explained by assuming a thrust fault striking

almost north and south with upthrow on the east and passing between the Palmer and Howe wells on the upthrown side and the Kemp well on the downthrown side. However, although such a fault would meet the requirements indicated by the logs of the wells mentioned, the explanation is not particularly intriguing because one would normally expect a thrust fault to be approximately parallel with the strike of the fold in this territory rather than directly transverse to the strike of the fold.

Another possible explanation is that the structure is contorted and somewhat infolded. This explanation, however, fails even further to agree with what would be expected than does the suggested explanation involving a north-south striking thrust fault.

A third possible explanation is that there may have been miscorrelation of the formations. This, however, seems less probable than that there actually is a complex structural condition.

It is hoped that when drilling has furnished more complete data Mr. Gaddess or some other author will furnish us with the correct explanation of this interesting condition.

RICHLAND GAS FIELD, RICHLAND PARISH, LOUISIANA[1]

DUGALD GORDON[2]
Shreveport, Louisiana

ABSTRACT

The Richland gas field was the second field discovered in northeastern Louisiana. The discovery well was completed in December, 1926, 10 years later than the discovery of the Monroe gas field, 10 miles northwest. Gas is produced in an area of more than 75 square miles at depths ranging from 2,320 to 2,500 feet in Upper Cretaceous beds composed of red gumbo, gray tuffaceous sand, and sand. There is also a gas horizon several hundred feet below the regular "pay" and in the upper part of the lower Glen Rose formation. The structure on the base of the Midway clays immediately above the pay horizons is that of an irregular dome elongate north and south, with the least dip away from the field located at the northwest side and toward the Monroe field.

The drilling practice has been to set casing at 2,300 feet, then to drill to 2,450 feet and bring in the well. This custom necessitated, because of the nature of the pay horizon, the development of a method of tubing the wells under the existing high open flows and pressures which at the beginning were 1,125 pounds. By January 1, 1931, the field had produced 141,000,000,000 cubic feet of metered gas from 194 wells.

The marketing of production is now fully under way with gas from the Monroe and Richland fields moving through pipe lines to Atlanta, St. Louis, New Orleans, Houston, and intermediate cities.

INTRODUCTION

LOCATION AND RELATION TO OTHER FIELDS

The Richland gas field is of interest to laymen and the gas industry mainly because of the enormous impetus given by the field to the building of pipe lines out of the Richland-Monroe district, but its chief interest to the geologist has been in the problem of the identification of its producing horizon, the marked nonconformity of its structure with that of the near-by Monroe gas field, and the dissimilarity of their principal producing horizons.

The Richland field is in the northeastern part of Louisiana, in the Mississippi embayment. It is 45 miles west of Mississippi River and 40 miles south of the north line of the state. It is 10 miles southeast of the Monroe gas field and 40 miles northeast of the Urania oil field. The principal oil fields of northern Louisiana are at least 65 miles farther west, where the Upper Cretaceous section is more fully developed than

[1]Read by G. O. Grigsby before the Association at the San Antonio meeting, March 19, 1931. Manuscript received, March 26, 1931.

[2]Geologist, Brokaw, Dixon, Garner, and McKee.

it is in the Richland and Monroe districts. The location of the Richland gas field with reference to the general area is shown on Figure 1.

A large part of the oil produced in northern Louisiana comes from beds in the Upper Cretaceous. Oil is produced, however, at Urania from the basal Claiborne. Gas is produced throughout northwestern Louisiana from both Upper and Lower Cretaceous beds. Most of the gas produced at Richland and Monroe comes from the Upper Cretaceous.

ACKNOWLEDGMENTS

The data and conclusions in this paper are based on the results of the drilling in the Richland field by Moody-Seagraves and on data of the Louisiana Gas and Fuel Company, the Gulf Refining Company, and the Standard Oil Company of Louisiana. The paper has been read and supplemented by W. C. Spooner, consulting geologist.

HISTORY

The drilling of wells for water and the finding of showings of gas led to the drilling of the discovery well of the Monroe gas field in 1916 and the development of that field. As the area of this field is large, at least 375 square miles, there were no extensive wildcat operations for several years, until after the Urania oil field was discovered in March, 1925. This development created an interest in the area northeast of Urania along the strike of the beds. There was sufficient evidence of favorable conditions along this line in the area southeast of Monroe to justify the Gulf Refining Company in beginning drilling operations. This resulted in the completion of the discovery well of the Richland field in December, 1926, the Gulf Refining Company's England Planting Company No. 1, in Sec. 32, T. 17 N., R. 6 E., which had an open flow of 10,000,000 cubic feet and a closed pressure of 1,108 pounds. The total depth of this well was 2,340 feet.

Wildcat drilling east of Richland received some impetus from the success obtained at Richland. The net result up to this time in Louisiana has been the development by the Palmer Corporation of the Floyd gas field in East and West Carroll parishes, Louisiana.

During the early development of the Richland field most of the leases were in the hands of oil-producing companies. When it became evident that a gas field rather than an oil field would be developed, the gas rights were obtained by companies interested in production of natural gas and the development was continued. The completion of large gas wells encouraged the promotion of major pipe lines out of the Richland-Monroe district. By the winter of 1929-1930 gas was being delivered from the

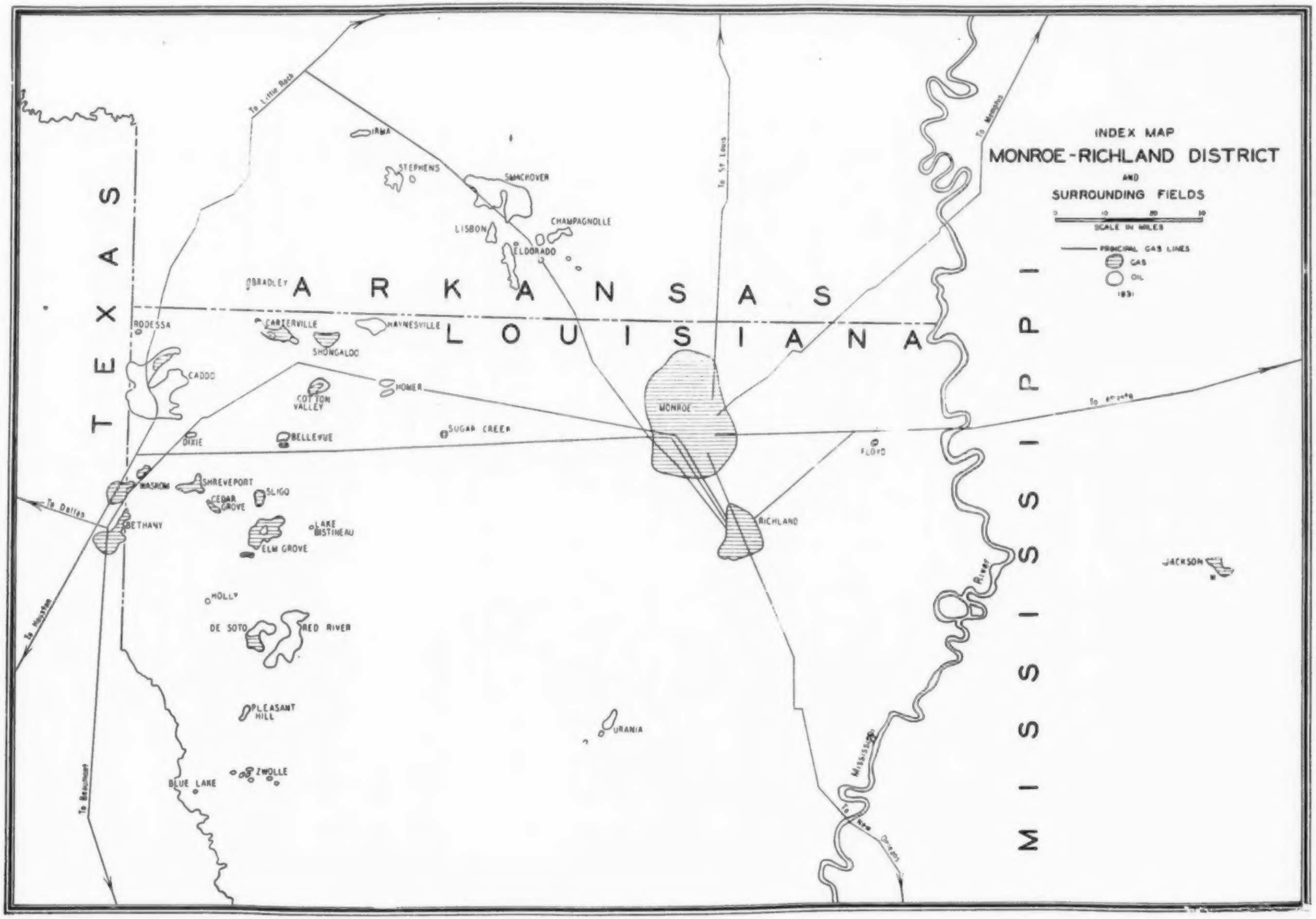
INDEX MAP
MONROE-RICHLAND DISTRICT
AND
SURROUNDING FIELDS
0 10 20 30
SCALE IN MILES
PRINCIPAL GAS LINES
GAS
OIL
1931
TEXAS
ARKANSAS
LOUISIANA
MISSISSIPPI
To Little Rock
To St Louis
To Memphis
To Atlanta
To Dallas
To Houston
To Beaumont
To New Orleans
Mississippi River
IRMA
STEPHENS
SMACKOVER
LISBON
CHAMPAGNOLLE
ELDORADO
BRADLEY
RODESSA
CARTERVILLE
SHONGALOO
HAYNESVILLE
CADDO
COTTON VALLEY
HOMER
DIXIE
BELLEVUE
SUGAR CREEK
MONROE
FLOYD
WASKOM
SHREVEPORT
CEDAR GROVE
SLIGO
BETHANY
LAKE BISTINEAU
ELM GROVE
RICHLAND
JACKSON
HOLLY
DE SOTO
RED RIVER
PLEASANT HILL
URANIA
ZWOLLE
BLUE LAKE

FIG. 1

Richland-Monroe district through lines having diameters as large as 22 inches to distant cities, including Atlanta, Memphis, St. Louis, New Orleans, and places in northeast Texas where the gas is compressed and moved to Houston and Dallas.

STRATIGRAPHY

GENERALIZED SECTION

A generalized section of the formations in the Richland field is shown in Table I.

TABLE I

GENERALIZED SECTION, RICHLAND FIELD

	Thickness in Feet
Quaternary	
Recent surface sands and gravels	110- 160
Tertiary	
Eocene series	
Claiborne group	
St. Maurice formation	100
Sparta sand formation	575
Cane River formation	220- 350
Wilcox formation	700-1,000
Midway clays	600
Cretaceous	
Gulf series (Upper Cretaceous)	
Monroe gas rock	70*
Ozan formation (Buckrange sand at base)	300
Brownstown marl	70
Tokio formation (producing horizon)	320
Comanche series (Lower Cretaceous)	
Trinity group	
Upper Glen Rose	780
Anhydrite zone	450
Lower Glen Rose ("Eubanks sand" in upper part)	900
Lower Trinity red shale and sand series	1,500

*Because of nonconformity of lower formations with the Midway and their consequent truncation, the amount of these lower formations penetrated will depend upon the location of the well.

SURFACE BEDS

The surface of the Richland field is highest along Boeuf River, where altitudes as high as 78 feet occur. The surface slopes away from the banks of the river to elevations as low as 65 feet, where the ground is swampy. There are many abandoned ox-bows of the river. The surface beds are recent sands and clays, overlying the St. Maurice formation of the Claiborne group.

EOCENE SERIES

St. Maurice formation.—The existence of the St. Maurice in the center of the field was determined as a result of the cratering of a well at Alto while drilling at a depth of 290 feet, blowing out quantities of marine shells. The beds of this formation, because of their clayey character, afford a seat for the first string of casing.

Sparta sand.—The Sparta sand has four fresh-water horizons, which are separated by thick beds of blue clay. The Sparta sand, including the beds of clay, has a recorded thickness ranging from 460 to 600 feet, averaging 575 feet in the producing field. The largest sand body is 230 feet thick and occurs at the base of the formation. The sand is white and fairly coarse-grained. Gravel beds occur at the base and in the three upper water horizons. The sands are so loose and friable that where a crater has been formed in a test drilling to the pay horizon it is necessary to exercise care in drilling through the Sparta sand in relief tests, as the sand beds accumulate gas and easily blow out, forming more craters.

Cane River formation.—The Cane River is the basal formation of the Claiborne group and has a thickness of 215 feet over the higher part of the structure. Northeast of the field a well in Sec. 15, T. 18 N., R. 7 E., records a thickness of 360 feet, and wells in the south end of the field record 270 feet of Cane River beds. These beds are commonly logged as blue or brown gumbos and rarely as sandy gumbo. Cuttings from tests show sufficient glauconite to justify the conclusion that the beds are blue and brown glauconitic clay. This clay offers an excellent seat for the second string of casing, the purpose of which is to case off the water in the Sparta sand.

Wilcox formation.—The highest bed in the Wilcox on the south flank of Richland yields a strong flow of artesian water, but this upper bed is not present in the field itself. Below it is a succession of beds of sand, sandy shale, clay shale, and lignitic shale. The Wilcox formation shows a total thickness of 1,000 feet at distances of 2 miles from the margin of the field, but in the field proper the thickness is not more than 700 feet.

Midway clays.—In the drillers' logs the Midway is distinguished from the Wilcox by the increased hardness of the beds, which are composed of hard gray to black shales, some fine sand in wavy leaf-like layers, siderite concretions, and in the lower part calcareous shale. The Midway is 600 feet thick and maintains that thickness throughout the area.

GULF SERIES (UPPER CRETACEOUS)

In the review of the Eocene, the formations have been described in descending order and this method will be continued. However, it is necessary to bear in mind that the highest beds of the Upper Cretaceous below the Eocene that are present on the margin of the field are not present in the field proper, where the highest bed is the gas-producing Tokio formation. Therefore, any information concerning the Cretaceous beds younger than the Tokio must be taken from tests drilled at and beyond the margin of the producing area.

Upper Cretaceous formations above producing horizon.—The relationship of the younger Cretaceous beds on the flank of the producing area is shown in Figure 2, a northeast-southwest cross section of the field. Although, as has been stated, these formations are not present in the field proper, they reach a known thickness of 420 feet within 5 miles of its southwestern margin. The highest of these pinched-out beds is the Monroe gas rock, a porous sandy limestone, which is readily identified in the southwestern and northern parts of the field. In the northwestern part of the field, gas is produced from this gas rock as well as from the tuffaceous beds of the Tokio below. In the southwestern end of the field, the Monroe formation does not reach a sufficient thickness on the structure to be productive. It is true that gas was found in this rock in one test well, Oliver's Hatch No. 1 in Sec. 2, T. 15 N., R. 5 E., which was abandoned as the well blew wild and could not be controlled, but an offset well failed entirely to produce gas at the corresponding depth. On the south side of the field the presence of the gas rock has not been determined, but in edge wells green sand beds known to occur below the gas rock are found; therefore, it is believed that the gas rock is present beyond the margin of the field. On the east side the test well in Sec. 22, T. 16 N., R. 7 E., had chalk rock, lime, and streaks of sand from 2,727 to 2,860 feet, which is believed to be the equivalent of the gas rock section. At the northeastern end of the field 75 feet of gas rock is present in the test well in Sec. 15, T. 18 N., R. 7 E. From the foregoing statements it is evident that the field is practically encircled by the Monroe gas rock with a thin section of the beds on the margin of the field and an increasing thickness away from the field.

The beds between the Monroe gas rock and the Tokio are shown on the southwest part of the cross section, where they reach a thickness of 290 feet. Their upper part consists of shale, ranging from clayey to sandy, with much green material. A sand near the base contains salt water, below which is a bed of shale. This sequence suggests the Ozan

formation, the Buckrange sand, and the Brownstown marl. Next come the beds of the producing horizon.

Principal producing horizon, lower part of Upper Cretaceous.—The principal gas-producing horizon is found at depths ranging from 2,320 to 2,500 feet below the surface. It consists mainly of beds of porous tuffaceous sand and tuff, siltstone, and red clay, of which the clay constitutes approximately 50 per cent of the formation. The total thickness of the gas-producing horizon is 300 feet. Gas is produced from four tuff beds. The greatest thickness of any bed is 29 feet, which is found in Sec. 36, T. 17 N., R. 5 E., whereas 7 miles south of this locality the bed has a thickness of only 6 feet. The producing beds extend as far northeast as a northwest-southeast line through the center of T. 17 N., R. 6 E., where the lowest producing bed of the Tokio is truncated and lies in contact with the Midway clay. It will be noticed on the map that the gas wells are limited on the northeast by the line described.

The tuffaceous sand is loose and friable so that a well flowing into the air is in danger of cutting the connections and bringing water into the producing horizons. The presence of salt water at Richland constitutes a much greater menace than its occurrence in the gas rock at Monroe.

Some wells inside the productive area have been failures probably because they were drilled at a location where the producing tuff beds were absent or lie below the salt-water level.

Age of producing horizon.—If the interpretation shown in Figure 2 is correct, the producing horizon is older than the Ozan formation and the Brownstown marl. It should therefore correspond with the producing horizons in the Rainbow City field, Union County, Arkansas, which are correlated with the Tokio formation of Austin age or the Woodbine sands of southwestern Arkansas, as defined by Dane.[1] These beds lie unconformably upon the Glen Rose formation of the Trinity group.

COMANCHE SERIES (LOWER CRETACEOUS)

The beds of the Comanche series above the Trinity group are seemingly not represented in the Richland field. The Trinity group itself is represented by 3,700 feet of formations which may be divided as follows: upper Glen Rose, Anhydrite zone, lower Glen Rose, and lower Trinity red beds. The cross section shows that these strata are separated from

[1]Carl H. Dane, "Upper Cretaceous Formations of Southwestern Arkansas," *Arkansas Geol. Survey Bull. 1* (May 7, 1929), cross section on Pl. III, and pp. 18 and 19.

the overlying Gulf series by a pronounced unconformity. The beds strike northwest and dip southwest at a rate of 200 feet per mile.

Upper Glen Rose.—A total thickness of 780 feet is shown for the upper Glen Rose, based on the log of Phillips *et al.* School Board No. 1 test in Sec. 16, T. 16 N., R. 4 E., 10 miles west of the Richland field. The character of the upper 325 feet of these beds is best known from cores taken in the Gulf Refining Company's Wayne Land and Timber Company No. 1. They consist of calcareous shales and fossiliferous shaly limestone, together with fine-grained, light-colored, red mottled siltstones and red clay. The beds contain specks of lignite, and in one test a bed of lignite has been logged.

The gas wells of the Richland field do not penetrate this formation in its entirety. The tests in the Richland field either do not enter this formation or penetrate it only where it is truncated; therefore, its thickness can not be stated accurately. The thickness is 300 feet, more or less, in the Gulf Refining Company's Rhymes No. 3, and in tests 2 miles farther northeast the beds are entirely missing.

Anhydrite zone of Glen Rose.—The similarity of sections through considerable distances is always of interest. A section in the Bethany gas field, Panola County, Texas, 130 miles west of the Richland field, is here presented for comparison with a condensed log of the anhydrite section of the Hope Producing Company's Eubanks No. 1 in Sec. 27, T. 17 N., R. 7 E. The presence of this anhydrite in a section of several thousand feet of red beds serves conclusively to identify the adjacent formation.

COMPARISON OF SECTIONS FROM EUBANKS NO. 1 AND BETHANY GAS FIELD

	Eubanks No. 1 Thickness in Feet	*Bethany Gas Field Thickness in Feet*
Anhydrite	28	5
Shale and limestone	155	248
Anhydrite	196	238
Limestone	60	67
Anhydrite	40	3

Lower Glen Rose, including producing "Eubanks sand."—Nearly 900 feet of lower Glen Rose beds are known in the field. This thickness is present in the Gulf Refining Company's Millsaps No. 1. These beds consist of gray sandy shale, thick red beds, and layers of fossiliferous limestone. The layers occur immediately above and below non-marine beds. The thickness of the individual red beds differs and in the upper

part of the formation decreases southwestward. Gray sandy limestone predominates in the lower part of the section.

A lower producing horizon was found in the "Eubanks sand" in the upper part of the lower Glen Rose. The discovery well in this sand is the Hope Producing Company's Eubanks No. 1 in Sec. 26, T. 17 N., R. 6 E. The sand was found from 2,927 to 2,936 feet. The initial open flow was 7,652,000 cubic feet and the closed pressure was 1,210 pounds. This test was completed September 9, 1929, and on January 1, 1931, had produced 21,281,000 cubic feet of gas. In a general way this sand can be correlated with the subanhydrite producing horizons of other fields in northwest Louisiana. The structural position of this sand in the steeply dipping lower beds is such that no very considerable producing area can be expected.

Lower Trinity red beds.—On the northeast flank of the Richland structure the log of the Moody-Seagraves' Jones No. 1 shows the Monroe gas rock beneath the Midway clays, as shown in the cross section in Figure 2. Underlying the gas rock is a formation of red beds from 2,767 to 2,856 feet. The correlation on the cross section interprets this formation as also underlying the lower Glen Rose and a part of the lower Trinity red shale and sand series. Data in adjacent areas indicate a thickness of at least 1,500 feet.

IGNEOUS ROCK

Igneous rock was first noticed in this district in Moody-Seagraves' Osborne No. 1 in Sec. 14, T. 15 N., R. 5 E., from 2,475 to 2,500 feet. It is a black rock identified as nepheline basalt.[1] Other tests in the field have entered igneous rock. The Magnolia Petroleum Company's Sartor No. 2 in Sec. 16, T. 16 N., R. 6 E., within the producing area, which was completed as a dry hole, penetrated the following section.

	Feet
Hard igneous rock	2,502-2,504
Weathered igneous rock	2,520-2,548
Hard igneous rock	2,548-2,611
Weathered igneous rock	2,611-2,633

A test in Sec. 7, T. 16 N., R. 7 E., the Industrial Gas Company's Ruston Drilling Company No. 1, penetrated igneous rock from 2,330 to 2,600 feet. Other wells on or adjacent to the Richland field encountered ig-

[1]Ian Campbell and A. D. Miller, "Nepheline Basalt in the Richland Parish Gas Field, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 10 (October, 1928), pp. 985-93.

neous rock at depths ranging from 2,300 to 2,500 feet. In the Evansville Investment Company's Welch No. 1, in Sec. 2, T. 14 N., R. 8 E., 14 miles southeast of the Richland field, the top of the Cretaceous was found at approximately 4,140 feet and igneous rock was cored at 4,270 feet.[1]

STRUCTURE

The structural features of the Richland field are not determinable from rocks at the surface, but may be determined from well records on the base of the Midway clays, which is equivalent to the top of the Tokio in almost the entire producing area. Figure 2 shows the structure contour map drawn on the base of the Midway clays. The contour interval is 40 feet and the figures give depths below sea-level. The structure is an anticlinal fold, its highest part being represented by the minus 2,260-foot contour covering the north-central part of T. 16 N., R. 6 E. The contours show a rate of dip of 80 feet to the mile on the southeast side of the field and lesser rates of dip on the other sides of the field. On the northwest, only a low structural saddle separates the Richland field from the Monroe field.

The position of the top of the Tokio in the producing area is shown on Figure 2, where the contours on the base of the Midway clays are the same as those for the surface of the Tokio. On the west and south sides of the field the dip of the Tokio is greater than that of the base of the Midway, which condition makes a place for the Monroe gas rock, the Ozan formation, and the Brownstown marl between the Midway and the Tokio, as shown on the cross section. The limits of the field indicate the line along which the basal Tokio beds have been truncated.

There is also an unconformity between the Tokio formation and the upper Glen Rose, the truncated edges of the Glen Rose formation having steeper dips than the Upper Cretaceous beds. The structure of the Glen Rose anhydrite is known approximately in T. 17 N., R. 6 E., where tests drilled through it indicate a strike of N. 25° W., and a southwest dip of 200 feet to the mile.

PRODUCTION

Completion of wells.—The common practice in the Richland field is to set 200 feet of 12-inch casing to exclude surface water. A second string of 8-inch casing is set in the basal Cane River to exclude the water in the Sparta sand. Six-inch casing is set at 2,300 feet. The wells are completed with or without tubing. Where wells are completed without

[1]Communication from J. Y. Snyder.

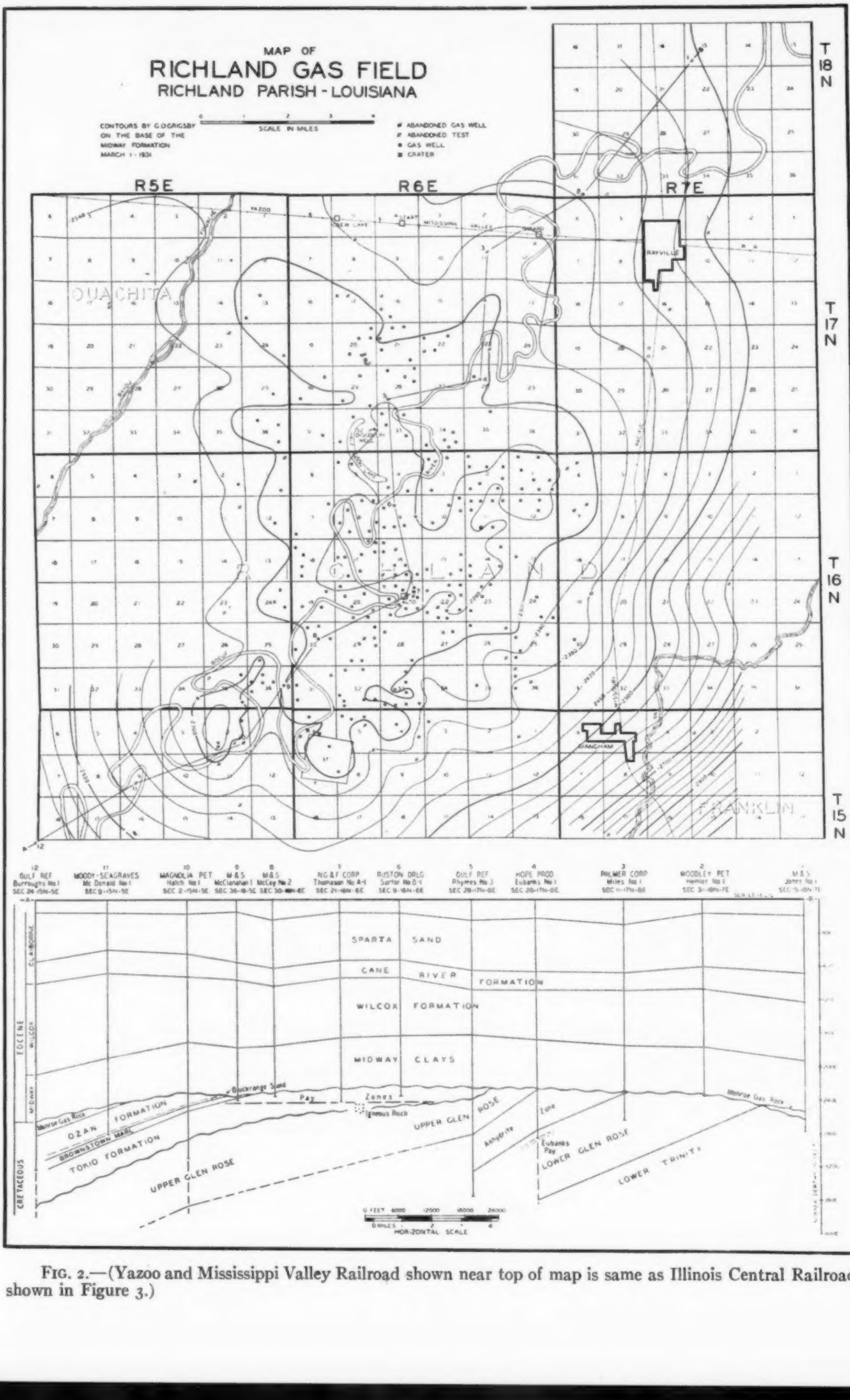

FIG. 2.—(Yazoo and Mississippi Valley Railroad shown near top of map is same as Illinois Central Railroad shown in Figure 3.)

tubing they are allowed to clean themselves before tubing is run, though no water is present. At this time practically all wells produce through tubing. The advantages of this method are that the wells can meet increased demand for gas and, if water is drawn into the well, it can be handled by the tubing acting as a syphon. In order to run tubing after completion it was necessary to develop a method whereby this could be done against the pressure and high open flows without opening the well. Where wells were opened the loose sand tuff rapidly cut the connections. A method for tubing the wells was successfully devised by The Southern States Company, Inc., and their method has since been used in other fields. The tubing is run against the working pressure of the well with no loss of production and in most wells with no interruption of feed.

Producing area.—The total producing area of the Tokio is 75 square miles and the total producing area of the Monroe gas rock is 2 square miles. The producing area of the Eubanks sand is as yet that covered only by the discovery well in that sand.

Water conditions.—Water conditions vary from west to east across the field. In the central and western parts of the field, water is found at 2,500 feet and in the southeastern part at 2,475 feet. All wells are equipped with tubing and syphons to handle salt water.

Initial production.—In the early development of the field the initial open flows were as high as 65,000,000 cubic feet and closed pressures were 1,125 pounds. These open flows were determined by the conventional Pitot-tube method of measuring open flows. Experiments[1] in passing the gas through meters under different back pressures made in the Richland gas field prove that wells having open flows of 65,000,000 cubic feet are actually passing volumes of gas far in excess of that amount.

Production statistics.—The metered production records from 194 wells in the Richland gas field measured on a basis of 10 ounces above atmosphere are as follows.

	Cubic Feet
1927	2,000,000,000
1928	10,000,000,000
1929	42,000,000,000
1930	87,000,000,000
Total	141,000,000,000

The effect that this production has had so far on pressures is shown in Figure 3. The map was prepared from the results of the semi-annual

[1]Donald E. Fuellhart, "Determining Open Flow Capacity," *Oil and Gas Jour.* (May 9, 1929), pp. 129, 132, 135.

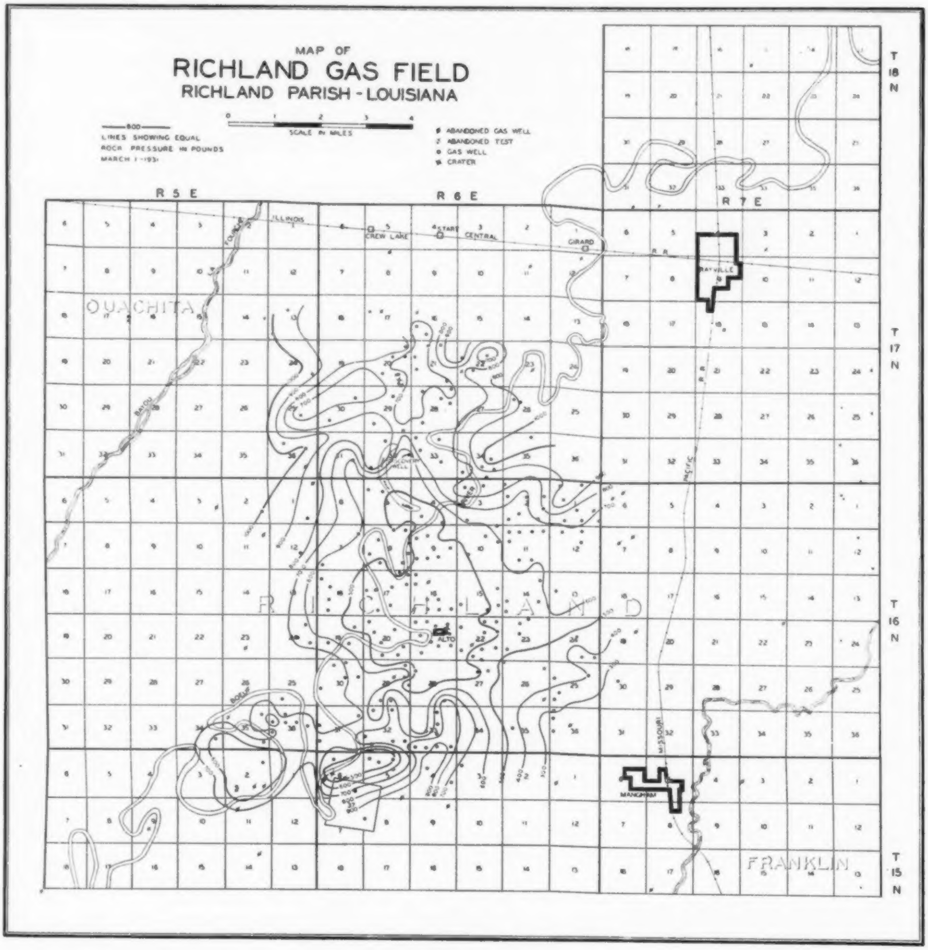
MAP OF
RICHLAND GAS FIELD
RICHLAND PARISH - LOUISIANA
LINES SHOWING EQUAL ROCK PRESSURE IN POUNDS MARCH 1 - 1931
SCALE IN MILES
ABANDONED GAS WELL
ABANDONED TEST
GAS WELL
CRATER
R 5 E
R 6 E
R 7 E
T 18 N
T 17 N
T 16 N
T 15 N
OUACHITA
RICHLAND
FRANKLIN
RAYVILLE
ALTO
MANGHAM
CREW LAKE
GIRARD
ILLINOIS
CENTRAL
MISSOURI
PACIFIC

FIG. 3

gauge taken by the Louisiana Department of Conservation in September, 1930, at which time the average numerical closed pressure for 196 wells was 611 pounds. The lowest pressures are in the vicinity of the craters, because wells so situated have produced a larger volume in order to reduce the flow of gas from the cratered area. Approximately 3,000,000 cubic feet of metered gas has been recovered per acre.

The production of gasoline per million cubic feet varies from 270 gallons in the north-central part of the field to 500 gallons in the southeastern part.

Marketing.—The major pipe lines in the Richland and Monroe districts are shown in Figure 1. These lines have a total length of 2,600 miles and carry gas to Atlanta, St. Louis, New Orleans, Little Rock, Dallas, and Houston. In addition, there are several smaller lines serving industries and towns. The total metered gas that had been produced in the Richland and Monroe districts by January 1, 1931, was approximately 1,325,000,000,000 cubic feet. Until recently most of the gas was used for carbon black, but the need of gas for pipe lines, together with other economic reasons, had in 1930 reduced the amount of gas used for that purpose to less than 40 per cent of the total production.

EXCEPTIONAL ASSOCIATION OF OIL AND WATER IN PRODUCING ZONES AT REFUGIO, TEXAS[1]

R. G. MAXWELL[2]
Paducah, Texas

ABSTRACT

The Refugio gas field was discovered in 1919. In July, 1928, the first oil well was completed and since that time Refugio has become one of the important Gulf Coastal fields. Water is commonly found above the oil and gas or between them. The variable porosity and overlapping of sand lenses are believed to account for this exceptional association of oil and water, and probably account for the erratic production and expensive development.

INTRODUCTION

The Refugio field is approximately half way between Galveston and Brownsville on the southwest Gulf Coastal Plain of Texas. In its present stage of development the field proper occupies an area approximately 4½ miles square, practically all of which lies within the Refugio Town Grant, Refugio County, Texas.

Gas was discovered in this area in 1919, but not until July 28, 1928, when the Texas Gas Company's Clint Heard No. 1 was completed for 700 barrels of 24° Bé. gravity oil, did it claim attention as a prospective oil field. Development has progressed rapidly since that time, and during 1930 the field produced 11,677,000 barrels of oil from 210 wells. Five different sand horizons have proved productive, ranging in depth from 3,600 to 6,500 feet.

Thanks are due the Phillips Petroleum Company for information obtained from their records, for assistance in the preparation of the illustrations, and for permission to publish this article. The writer also wishes to express his appreciation to W. Armstrong Price for his helpful suggestions, and to W. J. Newell for his aid in the preparation of this paper.

GENERAL

The surface beds in the Refugio field and its immediate environs are believed to be Lissie and younger in age. The oldest formation pen-

[1]Read before the Association at the San Antonio meeting, March 19, 1931. Manuscript received, March 8, 1931.

[2]Merry Brothers and Perini. Formerly geologist, Phillips Petroleum Company, Refugio, Texas.

etrated has been identified as upper Jackson. All oil produced to date has been from the Catahoula-Gueydan and older formations, although several productive gas sands above the first oil horizon are found between 1,100 and 3,600 feet (Table I).

TABLE I

STRATIGRAPHIC COLUMN, REFUGIO FIELD, TEXAS

	Formation		*Thickness in Feet*
PLEISTOCENE	Beaumont Lissie Reynosa	Undifferentiated	1,700
PLIOCENE	Lagarto		
MIOCENE	Oakville Catahoula-Gueydan		1,600 600
OLIGOCENE	Marine phase (upper Frio ?) Frio Lower Oligocene		800 1,400 1,200
EOCENE	Upper Fayette (penetrated)		800

The rotary method of drilling is used entirely throughout the field, and very little coring is done except in wildcat wells, deep tests, and near the pay horizons. Coring is commenced in most wells after the sand has been encountered with the regular drilling bit; consequently, little dependence can be put on most of the sand tops.

The last string of casing is cemented below the gas or water sand, which in many places overlies the oil sand, and preferably in a shale break which is present in most parts of the field immediately above the oil.

The heavy oil (24° Bé.) is produced from the 3,700-foot sand, which yielded 82 per cent of the 1930 production. This oil has a ready market due to its high lubricating and anti-knock qualities. Oils from deeper sands range in gravity from 36° to 62° Bé.

SANDS

Oil-bearing sand horizons below 3,600 feet are the only horizons discussed in this article, although six or more sands above 3,600 feet have proved commercially productive of gas.

3,600-foot sand.—The sand at the 3,600-foot horizon, which is considered to be basal Catahoula, is the shallowest and has been the most prolific oil producer in the Refugio field. It ranges in thickness from 50 to 300 feet. This horizon consists of sand lenses and sandy shales with irregular shale breaks. The sand is composed mainly of medium-grained, loosely consolidated quartz grains, angular to fairly well rounded, in part calcareous and in part ashy, containing some glass and a small amount of chert. The sand is commonly broken with impervious silt streaks which range from 1/8 to 1 inch in thickness. The shale is ordinarily olive-green.

5,400-foot sand.—This horizon includes what is commonly termed the 5,350-, 5,400-, and 5,700-foot sands, as they are very similar in character and are Frio in age.

The 5,400-foot sand is composed of non-calcareous, fine- to medium-grained, sub-angular quartz, frosted in part, with some chert; ordinarily fairly well cemented with siliceous material. In some parts of the field this sand is very ashy. It is of fairly uniform thickness, averaging 40 feet. This has been the second most productive sand in the field to date.

The 5,350- and 5,700-foot sands are believed to be lenticular and to occur only on the east side of the field. They range from 10 to 30 feet in thickness and are relatively unimportant as producers, although several good high-gravity wells have been completed in them.

6,400-foot sand.—The 6,400-foot sand is the deepest producing oil sand in the field to date and has not been fully explored. The "pay" is believed to be lower Oligocene in age. The average thickness of this sand in wells where cored is 150 feet, broken only by thin shale beds. It is composed of medium-grained, sub-angular quartz with some chert; calcareous, ash, and lignite streaks are common.

WATER IN OIL-PRODUCING ZONES

Because of the lenticular and variable nature of the sand bodies at the producing horizons, the oil and gas production does not occur uniformly in the sand section. Although bottom and edge waters are present in the field, water is also known to occur immediately above the oil or gas in some sands, separated only by thin silt or shale streaks, and in some wells by ashy sand streaks. Only this exceptional occurrence of water above oil and gas or between pay zones is discussed. In some wells a water-bearing sand is present between overlying and underlying oil sands. The breaks are, in many places, so thin that the drillers or men who look after coring fail to notice them; therefore, many logs show water

sand grading into oil or gas sand. The variable porosity and areal extent of the sand lenses, both vertically and laterally, have made the field treacherous in so far as production is concerned.

The seeming lack of uniform gravitational separation of oil, gas, and water in each sand body as a whole, has undoubtedly caused a considerable loss to operators, for the occurrence of water in the top part of the sand has caused many wells to be drilled rather than cored through sands. Coring might have shown oil below breaks not detected in drilling.

At the 3,600-foot horizon thin silt streaks in the sand seem to be very effective as breaks. In many wells two or three silt streaks ranging from ⅛ to 1 inch in thickness separate the upper water from the oil and gas (Fig. 1). In some wells ashy sand streaks represent the breaks.

FIG. 1.—Core samples showing silt streak.

The cored sections of four wells, the farthest wells being only 1,500 feet apart, are shown in Figure 3. With the exception of well 3, all cores were examined and logged by the writer. Wells 1 and 3 were side-tracked and the logs marked *A* represent the core records of the side-tracked hole. The correlation of logs 3-*A* and 4 was checked by fluctuation of pressure of well 3-*A* during the coring of the sand in well 4 from 3,673 to 3,678 feet. Well 2 blew in wild 12 hours following the first completion of well 1, and after re-drilling well 1, sands which contained only gas before the blow-out of well 2 were found to contain oil and salt water afterward. The blow-out of well 2 was also the probable cause for the

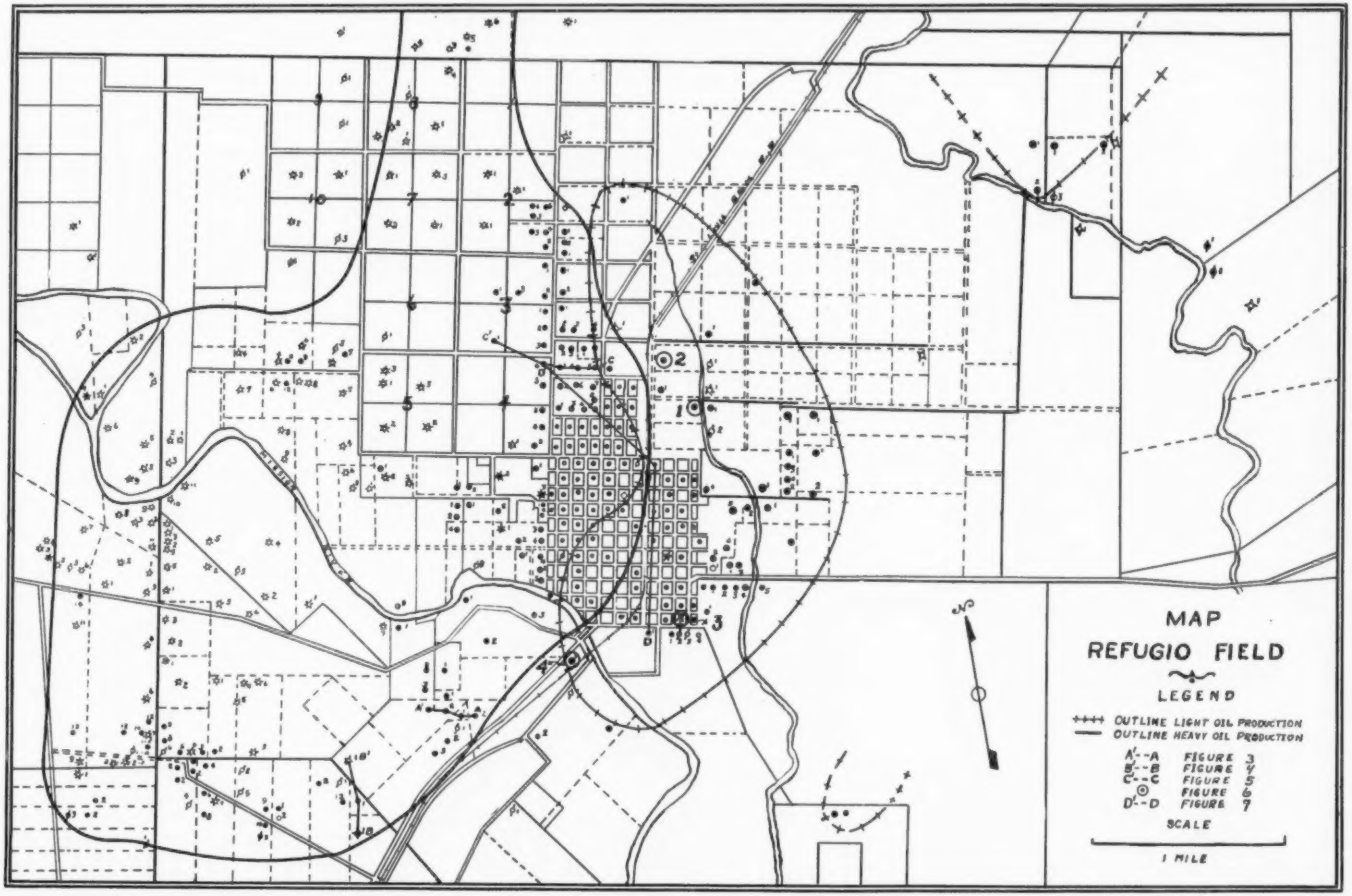
MAP
REFUGIO FIELD
LEGEND
OUTLINE LIGHT OIL PRODUCTION
OUTLINE HEAVY OIL PRODUCTION
A'--A FIGURE 3
B'--B FIGURE 4
C'--C FIGURE 5
FIGURE 6
D'--D FIGURE 7
SCALE
1 MILE

FIG. 2

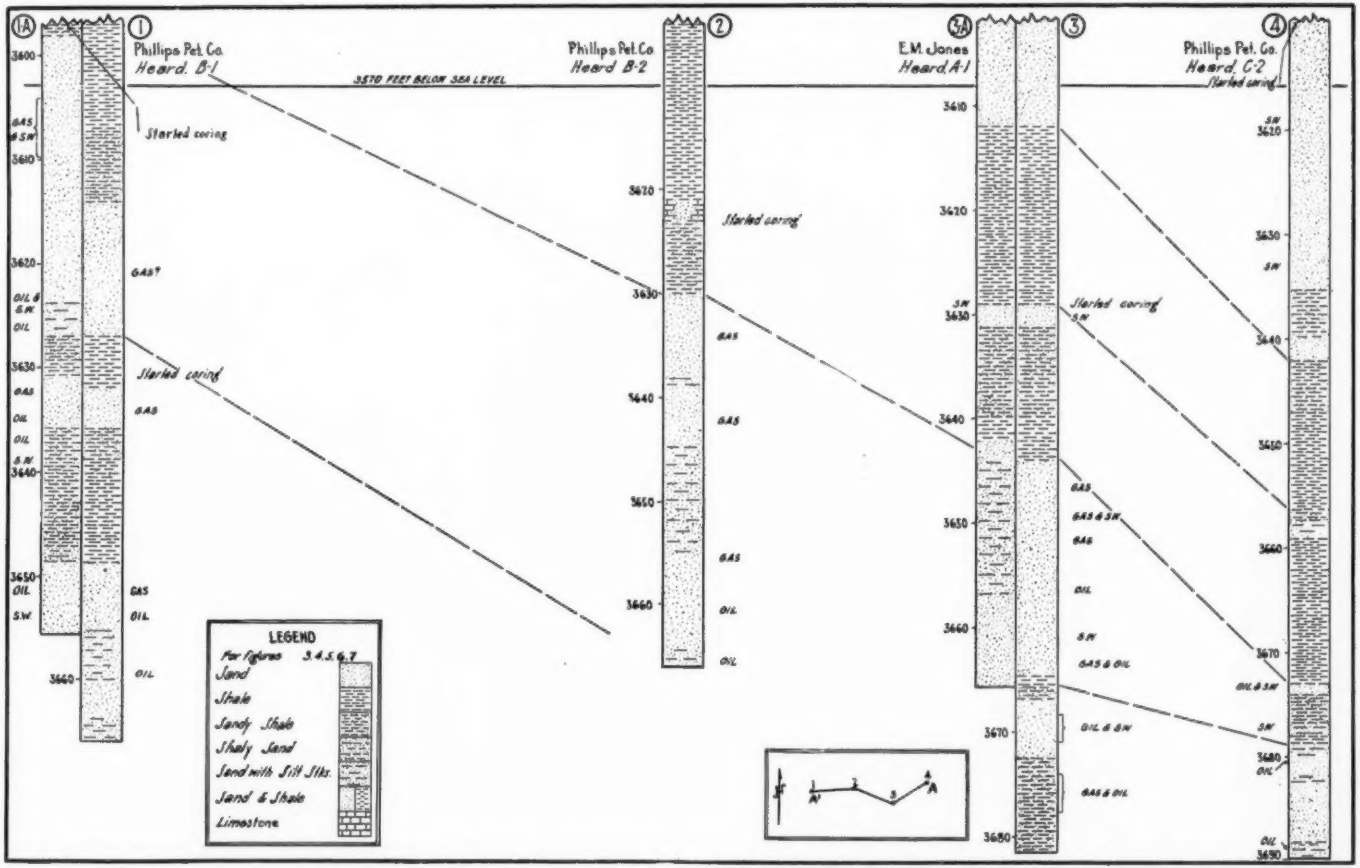

FIG. 3.—Core sections of four wells in Refugio field. See Figure 2 for location of $A'A$.

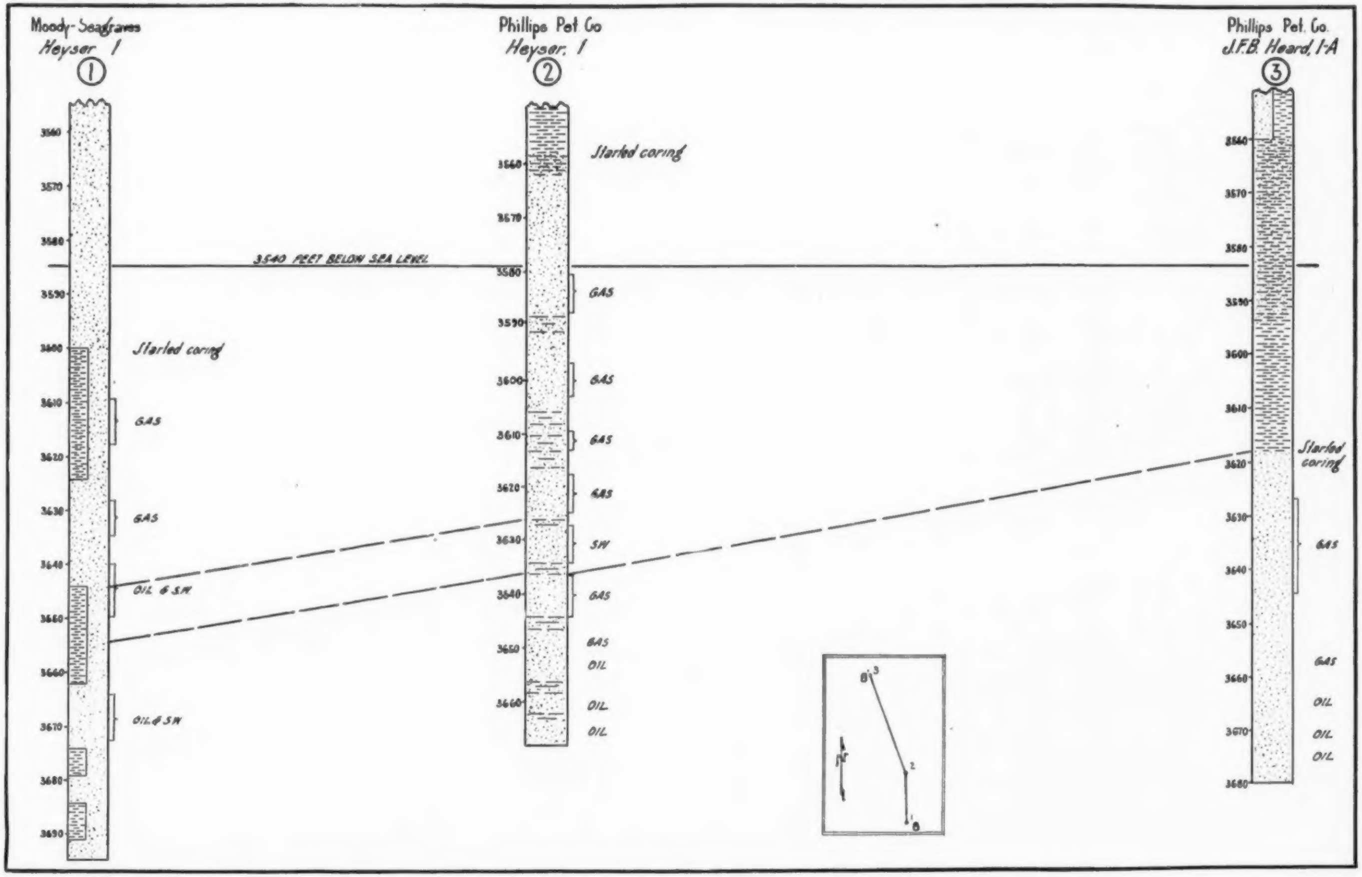

FIG. 4.—Core sections showing relations of oil and salt water. See Figure 2 for location of *B'B*.

higher oil level found in well 3 because of the loss of gas and relief of pressure during the time well 2 was out of control.

The occurrence of salt water above oil, separated from it only by a few thin sandy silt streaks, is shown in Figure 4. This figure also illustrates the importance of coring to obtain good sand records. Cores from wells 2 and 3 were logged and examined by the writer.

The lensing character of the sand bodies, which makes the water-level datum unreliable for operation purposes, is shown in Figure 5. Crooked-hole corrections are considered negligible, as acid-bottle tests on several wells failed to show more than a 3° deflection from the vertical.

From the 5,400-foot sand less detailed information is available; however, the observed breaks between oil, gas, and water have ordinarily been effected by ashy sand streaks or shale seams. Figure 6 shows the oil and water association as taken from drillers' logs, with the exception of wells 1 and 4, which are core records of this sand.

The 6,400-foot sand will probably be the most productive of the deeper sands explored, and, although of a more uniform character than the upper sands, it too has been proved lenticular. Upper water is also closely associated with the oil and gas in some of the wells which have penetrated this sand in different parts of the field. The separating breaks are ordinarily composed of hard impervious sand, ashy sand, or silt streaks. In Figure 7 are shown four typical logs of wells which were cored through most of this section. In the Phillips Petroleum Company's Jerry Riley No. 6, only three silt streaks approximately ⅛ inch thick were observed at the contact between the water and the gas found immediately below.

CONCLUSION

The exceptional occurrence of salt water above oil and gas in this field is probably caused, at least in most wells, by the overlapping of sand lenses which are separated only by thin silt streaks, shale streaks, or ashy sand beds. In some wells this association is effected by blowouts near by. It seems to the writer that this association of oil and water in the Refugio field is probably common to all Gulf Coastal fields where lenticular sands predominate.

There is need, in the Gulf Coastal territory, of extensive laboratory studies of subsurface conditions to determine as far as possible the effect of sedimentation as compared with structure and its relation to the accumulation of oil and gas.

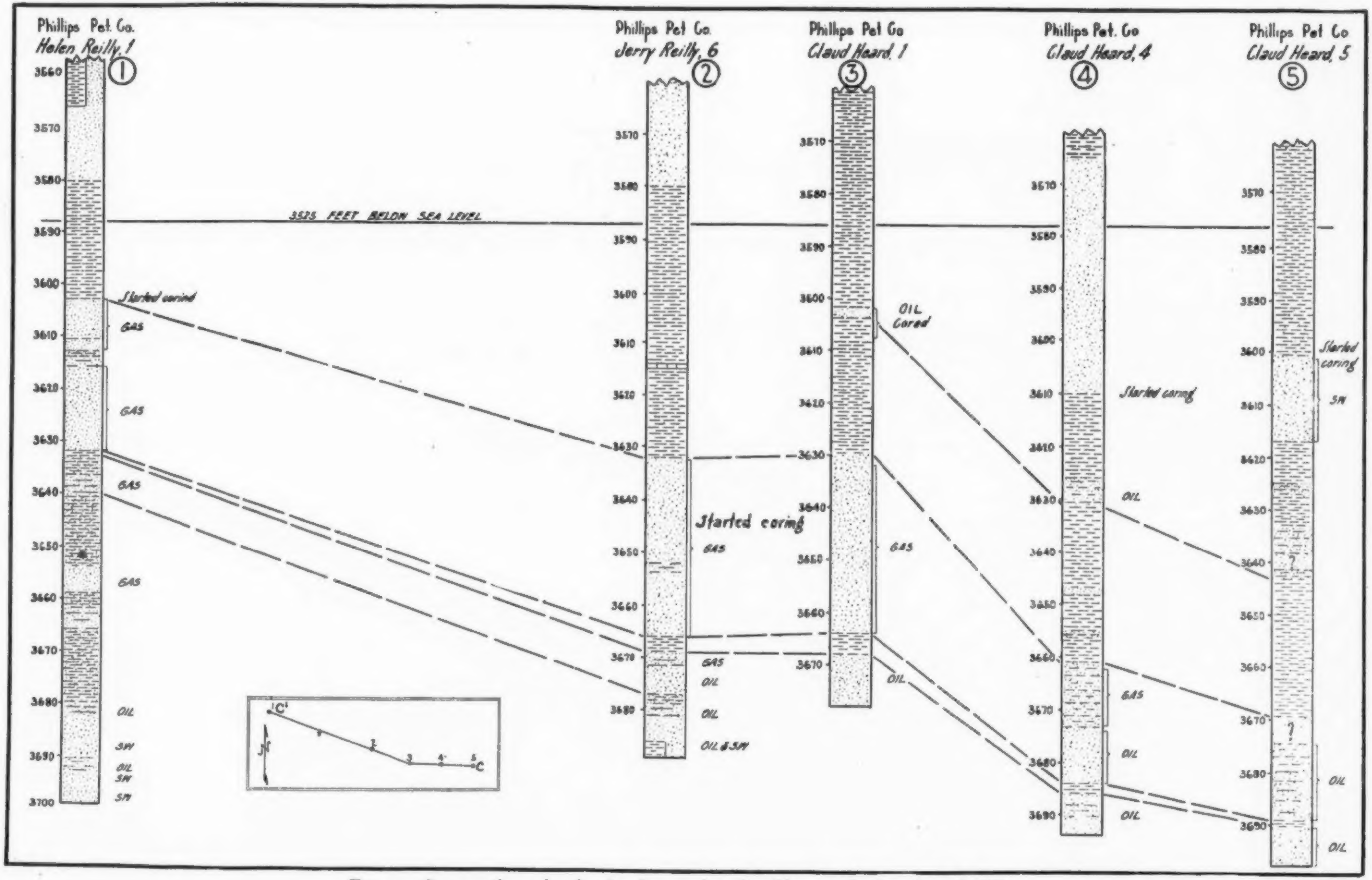

FIG. 5.—Core sections showing lensing sands. See Figure 2 for location of $C'C$.

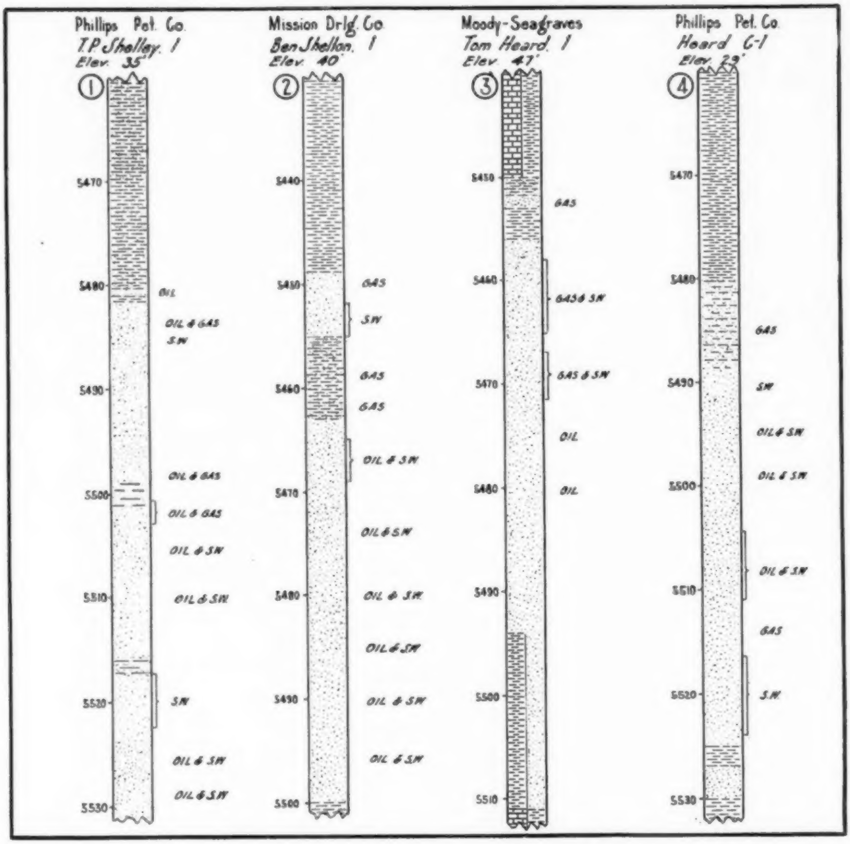

FIG. 6.—Core sections showing oil and water association. See Figure 2 for location.

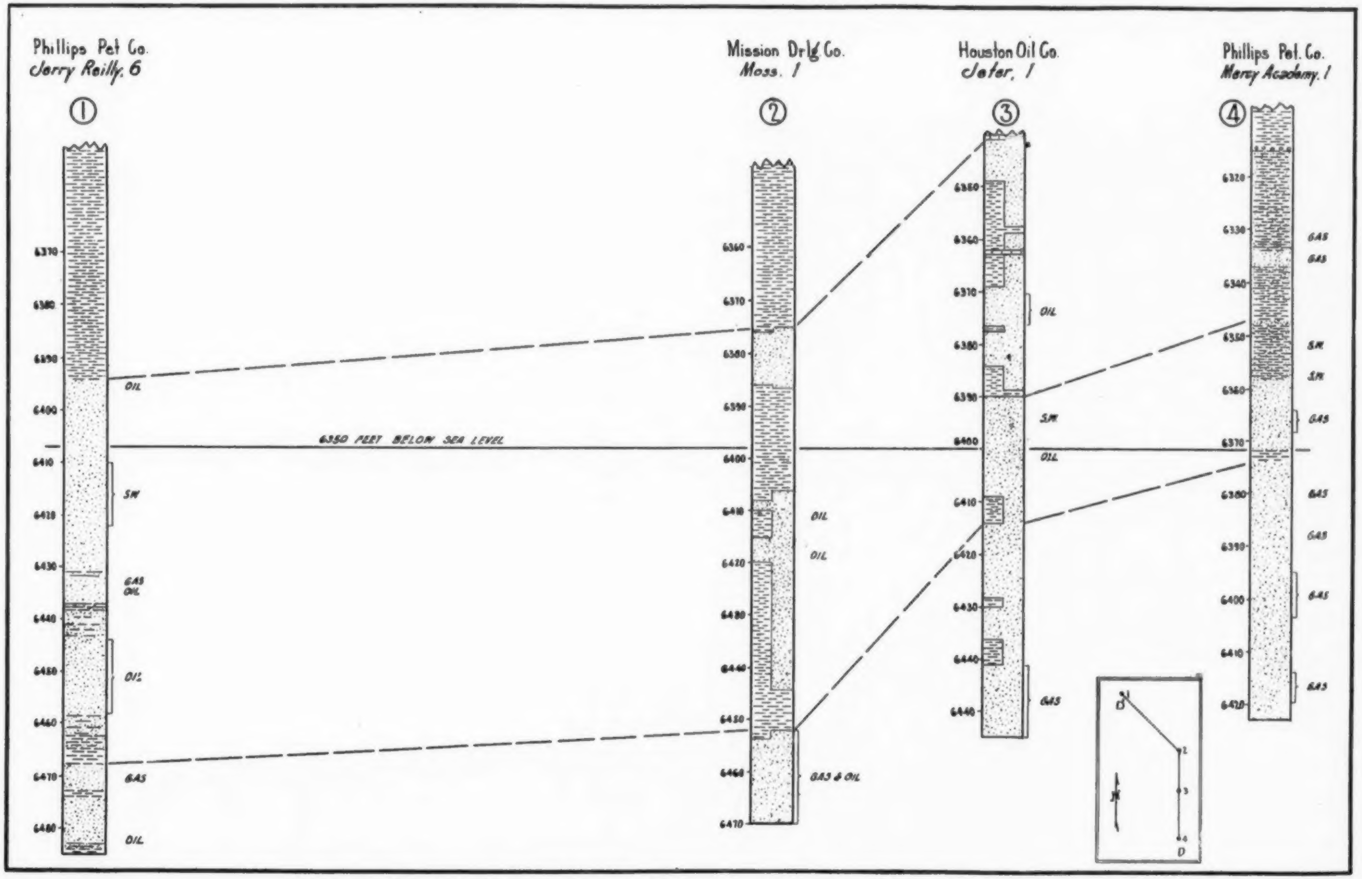

FIG. 7.—Four typical logs of wells in Refugio region. See Figure 2 for location of *D'D*.

DISCUSSION

W. Armstrong Price, Corpus Christi, Texas: The same condition of water above oil was noticed in a near-by field, in at least one well.

Cores of the 2,400-foot horizon at the south end of the Saxet oil and gas field, Nueces County, Texas, 30 miles south of the Refugio field, show this condition. The cores observed were from the Pearson Properties, Inc., No. 1 State National Bank land. Sulphur water was cored immediately above oil-bearing sand and shale. The well did not become a producer, probably because of faulty measurements when the coring was done. On a screen test it made salt water.

E. H. Finch, San Antonio, Texas (written discussion received, June 13, 1931): The great importance of sufficient coring in such a field as Refugio, where there is great irregularity in the sand zones, is well emphasized by Mr. Maxwell in this interesting paper. With reference to the stated thicknesses of the sand, a large number of drillers' logs show a sandy series ranging from 20 to 40 feet in thickness, more than one member of which is productive in the field. Some difference of opinion exists as to the relationship of oil, gas, and salt water in the 3,700-foot sand. Attention is called by critics of geology to the fact that much water is produced with the oil on certain leases in the heart of the field at some distance from normal edge-water line. This is a normal condition, however, for the reason that the dip in the 3,700-foot area is no greater than the thickness of the sand recorded by drillers in many wells. If a well situated on the inner edge of the oil-producing area be drilled a few feet deeper than the average well, it may easily reach water in the lower part of the sand, whereas wells on the outer edge of the producing area will find the same water high in the sand. There is nothing mysterious about this relationship between oil and edge water. It is the normal occurrence in practically all oil fields which contain salt water, and the manifestation is complicated at Refugio because of greater irregularity, lensing-out, and relative flatness of the sands.

GEOLOGICAL NOTES

CRETACEOUS CHALKS, TEXAS AND ARKANSAS

The writers have been studying certain Cretaceous chalks of Texas and Arkansas during the past 4 years. Joseph A. Cushman is now working on the material thus accumulated and as fast as he completes specific identifications and illustrations the writers will discuss the stratigraphy and subsurface aspects of the various chalks. One paper is practically ready for publication. Certain preliminary notes on stratigraphy such as the following may be published in the *Bulletin* of The American Association of Petroleum Geologists.

Micro-faunas are exceptionally good for accurate correlation, if care is taken to notice variations due to time and character of sedimentation and to other factors which influenced life and which are ordinarily considered in other branches of paleontology.

The Ector chalk is of lower Austin age and correlative with the lower Austin chalk of the Balcones region. It crops out in East Texas and is the chalk commonly called "Austin" in wells drilled on the east side of the East Texas geosyncline.

In certain places in the Balcones region the body of chalk commonly called Austin contains Ector (lower Austin), middle Austin, and Taylor faunas. Therefore, it seems that in some places chalk deposition continued into Taylor time and that the micro-fauna changed in spite of this. In other places the lime deposition changed to marl deposition and the fauna changed to Taylor at practically the same time. In still other places lime deposition changed in middle Austin time to marl and mud, and, although the fauna did change, it did not become Taylor in aspect until somewhat later.

The Gober chalk, occurring on the outcrop and in wells in north East Texas, is a lower Taylor tongue and not a part of the true Austin chalk. In several respects it is more closely related to the lower Pecan Gap chalk than to the Austin and is intermediate in position.

The Pecan Gap tongue belongs to the Annona chalk, but in many sections in wells in East Texas the upper part as exposed at White Cliffs (Sevier County, Arkansas) is poorly developed, although in other places a chalk very close above the Pecan Gap contains a fauna which has a Saratoga aspect.

The micro-fauna of the type Saratoga chalk is more closely related to the Taylor (Marlbrook) underneath than it is to the Navarro (Arkadelphia) above, if the presence of common characteristic Taylor (Marlbrook) *Foraminifera* and the lack of the common characteristic Navarro (Arkadelphia) *Foraminifera* are sufficient criteria. The persistent Nacatoch sand above the Saratoga seems to represent a greater faunal break than the thin glauconite at the base of the Saratoga. This chalk extends from south-central Arkansas, through northwestern Louisiana, into the east side of the East Texas geosyncline. It is more widespread as found in wells than outcrops suggest.

It is evident that chalks, like shales and sands, tend to be lenticular both on a small and a large scale, not because of unconformities, but rather because of differences in kinds of deposition. Bases of chalks under consideration seem to be more closely related than tops, although there are many marked exceptions.

Much of this summary has been more fully presented at Baylor University and before the Fort Worth Paleontological Society and this is a reply to the inquiries concerning the plans for presenting this data.

N. L. Thomas
E. M. Rice

Fort Worth, Texas
June 24, 1931

DISCUSSION

YEAGER CLAY, SOUTH TEXAS

In connection with the proposal of Julia Gardner and A. C. Trowbridge in the April issue of this *Bulletin* (page 470), that the term Yeager clay be hereafter used to designate the lithologic unit overlying the Fayette sandstone in south Texas and consisting of dominantly non-volcanic clays of various colors, the president of the San Antonio Geological Society, Herschel H. Cooper, appointed a committee of geologists to consider the matter of this formation name. Members of the San Antonio Geological Society and members of this committee have done much field work during a period of several years in the area where these clays are exposed through a distance of many miles along Nueces River in McMullen County.

The committee finds that the members of the Society are practically unanimous in their objection to the use of the name Yeager for this clay series for the following reasons: (1) the name Yeager is, unfortunately, so similar to the name Yegua, the formation directly below the Fayette (the Yeager lying directly above the Fayette), that misunderstandings and errors will probably result if the term is used in telephonic or other oral communications or in handwriting; (2) a review of the literature does not seem to justify the assignment of a new name to these clays.

The first objection (1) needs no explanation, but with respect to (2) it may be stated that 20 years ago, in 1911,[1] E. T. Dumble recognized the Frio clay in its superposition on the Fayette as it is now recognized, the following being quoted from his paper.

> It is proven, therefore, that the deposits between the Angelina and the Neches along this line are not, as we originally understood them, a single group of clays equivalent to the Yegua, but two groups of *clay* deposits separated by beds of sandstone which, taken together, are the direct continuations stratigraphically of the Yegua, Fayette and Frio of the western region. So far as known they are practically unfossiliferous in this vicinity.

Thirty-seven years ago, in 1894,[2] Dumble referred to the Frio clay in the following terms.

> Frio clay—the Fayette subdivision passes upward into a series of *gypseous clays* with sand and sand rock, differing greatly lithologically from the underlying beds. This subdivision is therefore proposed for them. According to Kennedy, they are not present (in this form at least) on the Neches River, but I found them well developed on the Frio and Nueces.
>
> The clays are dark-colored, greenish gray, red or blue, usually massive, with quantities of *gypsum* and with *calcareous concretions* arranged in lines, giving them a stratified appearance. The sandy clays are laminated and bedded, green, red, or blue in

[1] *Trans. Texas Acad. Sci.*, Vol. 11 (1911), p. 51.

[2] *Jour. Geol.*, Vol. 2, No. 6 (1894), pp. 554-55.

color, and interbedded with brown or green sandstone which is concretionary and, in places, highly indurated. Brown sands overlie these and are followed by laminated chocolate clays containing *concretions of crystalline limestone* with *manganese dendritions*. These clays weather white, as at the mouth of the Frio.

Dumble was obviously not describing a volcanic series of rocks in his reference to clays with gypsum in quantities and with calcareous concretions; in fact this description by Dumble fits very well the description of the Frio clays given by Bailey,[1] who states that:

The Frio consists almost entirely of very soft and plastic, *gypsiferous*, creamy, green to light grayish green and purplish pink clays or variegated pink and green clays. * * * Many beds contain numerous creamy-white *calcareous concretions* * * *.

Similarly, it is obvious that in Dumble's description of the beds above the Frio clays which consist of clays with concretions of limestone with manganese dendritions, he was referring to the beds described 32 years later by Bailey[2] as in the lower Gueydan overlying the Frio clays, which description reads as follows.

The clay (in the Fant member of the Gueydan) carries many elliptical pinkish to whitish dense textured to granular calcareous and siliceous concretions up to 10 cm. in diameter. *Dark splotches* and *dendrites of manganese oxide* are common along fracture surfaces throughout the concretions.

It is clear, therefore, as stated by Bailey,[3] that the Frio of Dumble includes both the Frio and Gueydan of Bailey, and the statement of Julia Gardner and A. C. Trowbridge that Dumble's description included only outcrops of the volcanic series is not correct. It is therefore not necessary, as suggested, to retain the name Frio for the volcanic series only; if this were done it would not seem to be in accord with the original intent of Dumble. It is quite possible that because of rarity of outcrops of the Frio clay, the typical exposures cited by Dumble between Weedy Creek and Oakville on Atascosa and Frio rivers, and on the Nueces south of Tilden, showed more of the volcanic series than the lower beds, and it does not seem that a "type locality" has been selected by Dumble from the wide area of his typical exposures. The particular locality mentioned as at the mouth of the Frio where the clays of the lower Gueydan of Bailey weather white, should obviously not be called the type locality of the Frio clay.

That Dumble included in the Frio the volcanic series above the clay is evident from the following quotation.[4]

The Frio *group*, which succeeds these (beds of the Fayette), consists of *gypseous* clays with sands and sand rock. The clays weather white, although when wet they may be green, blue, red or yellow. They contain concretious of limestone with *man-*

[1]Thomas L. Bailey, "The Gueydan, a New Middle Tertiary Formation from Southwestern Coastal Plain of Texas," *Texas Univ. Bull. 2645* (1926), p. 45.

[2]*Op. cit.*, p. 71.

[3]*Op. cit.*, p. 10.

[4]E. T. Dumble, "A Revision of the Texas Tertiary Section with Special Reference to the Oil Well Geology of the Coast Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 4 (July-August, 1924), p. 427.

ganese dendrites. These are the surface beds from Fant City to Nueces River, a distance of over 10 miles.

The reference here to *gypseous* clays indicates that the Frio clay member is meant, whereas the mention of the beds weathering white very probably refers to the volcanic series (Gueydan). Thirty years had passed from 1894, when Dumble first named the Frio clay, to the year his "revision" of the section was published. He refers to his own data as "These *generalized* statements of well conditions in different parts of the coast country." It seems evident from the great amount of detail that has since become available on these formations that his descriptions and mapping were in fact generalized. Regardless of the slight apparent uncertainty as to the intent in Dumble's revision of the Texas Tertiary in 1924, his former descriptions, in 1894, when he named the Frio clay, should stand. The many wells which have been drilled during the past 10 years in the area between Frio River and the Rio Grande, and including a few wells which have been drilled in northern Tamaulipas, very clearly show that Dr. Dumble's original description of the Frio clays is accurate. Throughout this region we find a zone of gray, green, pink, and chocolate clays more or less gypseous, containing small lime concretions, which lie immediately above the top of the Fayette and below the zone which Bailey calls Gueydan. It is true that this zone (Frio) contains a small amount of volcanic material, but it is in smaller quantities than in either the Gueydan above or the Fayette below, and this volcanic material is not necessarily characteristic of this clay zone. The volcanic material is difficult to recognize in megascopic form; does not form distinct layers by itself, and is otherwise an accessory feature rather than the principal feature of the formation.

That Dumble, as early as 1894, differentiated the Frio clay part of the section from the overlying volcanic series (Gueydan) is evident from the following quotation.[1]

> The influx of large amounts of hydrous silica, beds of siliceous sinter and volcanic ash, and the development of cone-in-cone structure in the *upper portion* of these deposits is worthy of note as indicating the manner in which these Tertiary deposits became a land area.

Bailey[2] has shown that the Gueydan is equivalent, at least in part, and possibly entirely, to the Catahoula, as one formation can be traced into the other. Members of the undersigned committee have confirmed this equivalency and noticed in the field lateral gradations of the sandstone and clay facies of the typical Catahoula into the volcanic tuffs and fluviatile deposits of the Gueydan. The Catahoula itself, however, contains tuff and bentonite beds seemingly from the same volcanic source as the material of the Gueydan of Bailey.[3] It is therefore logical to extend the term Catahoula to include the beds of the volcanic series described by him, rather than to adopt a new name as he suggests, but it would not be correct to retain the name Frio for the volcanic part of the

[1] *Op. cit.*, p. 555.

[2] *Op. cit.*, pp. 147 and 178.

[3] *Op. cit.*, p. 178.

section only, in view of the fact that the term Frio clay has long been used for the clays. To introduce a new name would only cause confusion.

The bearing of the present known subsurface conditions on the relations at the surface is interesting and important.

According to Alva Christine Ellisor,[1] the Frio clays at Hockley contain volcanic ash and a few lower Oligocene *Foraminifera*, and in East Texas beds of volcanic ash occur in the clays just above the Fayette and below the Catahoula. In her opinion Dumble's original Frio exposed section includes two formations, as Bailey states, which are unconformable. In the subsurface, however, new members come in down-dip which are overlapped by younger members, with the result that coastward the formations thicken greatly. In subsurface sections the Catahoula or upper division is separated from the lower division or Frio clays by the fossiliferous middle Oligocene. The Frio clays contain a few lower Oligocene or Vicksburg *Foraminifera* and above the Fayette is a very fossiliferous Vicksburg several hundred feet thick which does not reach the surface in south Texas. Miss Ellisor's opinion is that the Frio as restricted to the lower clay section is certainly lower Oligocene in age and the Gueydan or Catahoula is younger than the middle Oligocene.

Other paleontologists have found that in wells in the Lucas field in Live Oak County the beds of the Frio have increased to a thickness of about 340 feet from about 150 feet at the outcrop and they have found in these beds *Foraminifera* which are definitely not Eocene but Vicksburg in age.

In view of these circumstances, it is the opinion of the undersigned committee that the term Yeager clay should not be substituted for Frio clay, but that the latter term should be retained to designate the clay beds lying above the Fayette and below the overlying volcanic series. It is also proposed that for the beds designated Gueydan by Bailey as the time equivalent of the Catahoula either the name Catahoula or Gueydan be used. If the names Frio and Catahoula are retained, no change will be required in formation names in this part of the geologic column as published by the U. S. Geological Survey in Professional Paper 126. A revision will be required, however, of Deussen's mapping of the Frio of south Texas, in order that the upper or volcanic part may be given its proper rank as a separate formation.

Committee: E. H. Finch, *chairman*
Phillip F. Martyn
Olin G. Bell
R. F. Schoolfield

San Antonio Geological Society
Herschel L. Cooper, *president*
San Antonio, Texas
June 19, 1931

[1]Personal communication.

ALBERTA SYNCLINE, CANADA

The paper by Theodore A. Link, which appeared in the May *Bulletin*,[1] presents some interesting hypotheses, but the well evidence, which forms the main basis of argument, is not convincing. Without some more intimate knowledge of the structure it is not perfectly safe to assume that the limestone lies at a depth of more than 12,000 feet on the eastern border of the Turner Valley structure, for, although the evidence from the British Dominion well No. 1 suggests something of this order, two other wells farther south by no means corroborate this.

In the Sterling Pacific well Dr. Link states that the beds penetrated beneath the main fault look very much like Upper Belly River, or the equivalent of the sandy Bearpaw shales. The writer has seen in these samples particles of maroon shale, which are very like those found in the Blairmore. This opinion is shared by at least two others who are well acquainted with the lithology of the formations of Alberta and who believe this to be Blairmore.

If the more general interpretations are correct, that the Paleozoic near the British Dominion well No. 1 is thrust into close proximity with the Belly River formation, and that in the Sterling Pacific well it rests on Blairmore, the intervening Mill City well, with the Paleozoic resting on Lower Benton, provides the connecting link for a main fault which has a gradually decreasing throw toward the south.

Turning now to the Anglesey-Lakeview well: in view of Dr. Link's statement (p. 498) concerning the difficulty of correlation within the Belly River, it would be more convincing if we could have some definite evidence provided to show that this well is really in Lower Belly River beds as stated; for, if it is not, the depth estimate could easily be in error by such an amount as to destroy the whole argument. As far as Dr. Link's statements go, the case for Lower Belly River beds in the Anglesey well is no more convincing than for those in the Sentinel well. A geologist who is well acquainted with these samples, and those of Alberta generally, when consulted by the writer, would not commit himself beyond stating that they are post-Benton.

A. J. GOODMAN

CALGARY, ALBERTA
June 4, 1931

Criteria for the definite distinction between the various formations of the Cretaceous section of Alberta are few and practically non-existent in print. For this reason one is confronted with difficulty in arriving at a definite conclusion regarding what formation is encountered in a drill hole which passes through a fault of such great displacement as the Turner Valley sole fault. This is particularly true if only a limited amount of drilling is done in the doubtful formation. In British Dominion No. 1, where the fault was encountered at a depth of 5,480 feet, and where drilling was carried to a total depth of 6,525 feet, we feel confident that Belly River or younger beds were encountered below the sole fault. In Sterling Pacific No. 1, less than 100 feet

[1]Theodore A. Link, "Alberta Syncline, Canada," *Bull. Amer. Assoc. Petrol. Geol* Vol. 15, No. 5 (May, 1931), pp. 491-507.

were drilled below the fault and the determination, as suggested in my paper on page 500,[1] is somewhat doubtful. However, in connection with Mr. Goodman's determination of these beds as Blairmore, on the basis of small "particles of maroon shale," it is in place to state that maroon and red shales are found in the pre-Cambrian of southern Alberta, as well as in the Kootenay, Blairmore, Upper Belly River, and the Willow Creek formations. Therefore, maroon shales are not to be taken as diagnostic unless found in combination with other known lithological characters.

In addition to the cuttings from bore-holes there are other factors which have much to do with the determination of formations. The "mechanical log," which means the manner in which the formation reacts to the drill, the rate at which hole is made, the nature of the mud in the slush pit, wear on bits, et cetera, are all taken into account by our field men in their determinations.

The Mill City well was not mentioned in my paper because of its doubtful significance with respect to the major sole fault. The drill passed from Paleozoic limestone through a fault into black, sandy Cretaceous (?) shales at a shallow depth of 5,011 feet. It is my opinion that this may *not* be the *major* sole fault, but a minor "slice fault," and that the former may lie at a greater depth.

The Sentinel well, not fully discussed by Mr. Goodman, ceased drilling at a depth of 5,840 feet in Belly River *or younger beds*, and, as pointed out in my paper, on page 500, it is a physical impossibility to reach the Paleozoic limestone at a depth shallower than 9,740 feet at this location.

The determinations of the Anglesey-Lakeview No. 1 samples are, like the determinations in the previously mentioned wells, based on years of field and laboratory experience by my associates and myself.

THEODORE A. LINK

CALGARY, ALBERTA
June 13, 1931

[1]Theodore A. Link, "Alberta Syncline, Canada," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931).

REVIEWS AND NEW PUBLICATIONS

Petroleum Development and Technology, 1931. By the Petroleum Division, American Institute of Mining and Metallurgical Engineers, Inc., 29 West 39th Street, New York, N. Y. (1931). 657 pp., illus., cloth. Price, $5.00.

The Petroleum Division of the A. I. M. M. E. held meetings in Tulsa, October 2 and 3, 1930, in Los Angeles, October 17, 1930, and the annual meeting in New York City, February 17-19, 1931, at which meetings papers were presented covering many of the latest developments and giving much technical information, each paper accompanied by a discussion. *Petroleum Development and Technology, 1931,* contains 65 papers classified in chapters as follows.

Chapter 1, Unit Operation of Oil Pools.—Most interesting facts are presented regarding unit operation, proration, and coöperative development programs, together with their economic aspects. In mentioning the present status of the petroleum industry, one of the authors makes it plain that we must have a well rounded program, giving due consideration to unit operation, proration, and regulation of imports or conservative marketing, before relief can be expected, and to make such a program successful there must be the closest coöperation between Government and industry.

Chapter 2, Production Engineering.—In this chapter are many of the technical papers pertaining to the production-engineering phase of the industry. The production engineer has previously been concerned chiefly with improving the efficiency of development and production technique as applied to the recovery of oil, but he is not faced with the need for preventing a waste of this natural resource. He is called upon to make a study of this economic problem and devise means for correcting the situation. Unit-operation and coöperative-development programs have made conditions ideal for the production engineer to make a more scientific study of economic-development problems.

Chapter 3, Engineering Research.—Here is considered some of the research work being undertaken by members.

Chapter 4, Production, Domestic and Foreign.—The summary for this chapter calls attention to the facts that the decrease of crude stocks in 1930 was accompanied by severely declining prices, and that many leaders of the industry now feel that over-production is more of a permanent condition than a temporary one, and that the study of methods for production control is most important.

Chapter 5, Economics.—Again we are brought face to face with the fact that supply and demand must be balanced and that excessive inventories are depressing. It is also emphasized that the industry is now responsive to sounder economic principles and to the necessity of modifying many old statutes that prevent economic operations.

Chapter 6, Refining.—Of exceeding interest is the statement that the chemist and engineer may assist in the present crisis by the further development of by-products.

Perhaps the point most clearly made and most prominently mentioned throughout this book is the present low status of the oil industry, which is due to over-production. The production engineer has a duty to perform in studying the problem in order that it may be handled in the most economical manner. Producers, the public, and our Government are urged to realize that the fullest coöperation in the application of new statutes, assisting in the application of unit operation, coöperative development, proration, and marketing are essential.

A. A. LANGWORTHY

TULSA, OKLAHOMA
June 26, 1931

"Résultats des récentes prospections de pétrole en Afrique équatoriale française" (Results of Recent Exploration for Oil in French Equatorial Africa). By J. JUNG and V. LEBEDEFF. *Annal. de l'Office National des Combustibles Liquides* (Paris), No. 4 (July-August, 1930), pp. 615-34, 5 photographs, 2 maps.[1]

The Office of Liquid Fuels of the French Government has been engaged in a systematic survey of the oil possibilities of the colonial domain of France. M. Lebedeff was assigned to the exploration of French Equatorial Africa and prospected the area in 1928 and 1929.

From Cameroon (Kamerun) southward into Angola the south Atlantic coast of Africa is bordered by a zone of sedimentary rocks. Because of the varying width of this zone the contact between the sedimentary and the crystalline rocks of the interior does not parallel the coast line. Though at some points it approaches or touches the coast, at others it is more than a hundred miles inland. In consequence the sedimentary rocks occur in several major areas which, because of their form, are generally called embayments. These embayments coincide in position with the major river systems of the region. From south to north the three principal areas are called the Cuanza (Kwanza), the Congo, and the Ogowé embayments.

The first of these is wholly in the Portuguese colony of Angola; the second in Angola, the littoral zone of the Belgian Congo, the Cabinda (Portuguese) and the southern part of French Equatorial Africa; the third is chiefly in French Equatorial Africa but extends northward into Spanish Guinea and Cameroon.

Indications of petroleum—seepages, tar sands, deposits of solid bitumens and salt springs—have been known to occur on this coast from the period shortly after discovery. At Pointe Noire, at the south end of French territory, shaly limestones contain asphalt in small cavities, and in quarries near the town heavy oil flows out of fissures in the rock. A thousand meters farther north, at Poumbou, are petroliferous sandstones and seepages along one of the rivers. In the Ogowé embayment there are springs carrying petroleum along Rombo N'Komi River and, near N'Kogho, wells from which the natives have collected and sold petroleum.

[1]Article translated by W. P. Haynes; review by W. B. Heroy.

The sedimentary section in each of these embayments includes Cretaceous and Tertiary strata. In French Equatorial Africa Lebedeff describes the following section as resting on the crystalline rocks of the African basement.

Age	*Description*	*Thickness in Meters*
Quaternary to Recent Post-Eocene	Clays and conglomerates, non-fossiliferous	150
Unconformity		
Eocene	Sands and sandstones, with shark teeth and some lamellibranchs and gastropods	500
Cretaceous		1,500
Senonian	Marly sandstones and shales, fossiliferous, representing the Santonian and Coniacian sub-stages	
Turonian	Fossiliferous limestones	
Cenomanian, Albian	Doubtfully represented by non-fossiliferous formations	
Basal—"Sublittoral sandstones"	Micaceous sandstones, more or less calcareous, associated with clayey or shaly marls, red, gray, or black. Age undetermined	250
Unconformity		
Crystalline basement		

He points out that there is much variation in the formations along the strike. The thickness is also far from uniform, the section at Fernand Vaz being measured in thousands of meters, and at Pointe Noire seeming to be much less. He considers that the region has been broadly folded with some attendant faulting. Few dips are more than 10°. The axes of the folds are approximately parallel with the crystalline contact. Detailed mapping is required to reveal the exact structure and this is rendered difficult because of the equatorial forest which extends over the entire area in unbroken density.

The author notes that evidences of petroleum are found in the "Sublittoral sandstones," in the Cretaceous, and in the Eocene. In each age, however, it is a slightly oxidized heavy oil. As the occurrences in the "Sublittoral sandstones" are much more widespread, he is inclined to believe that the oil originated in that formation and migrated into the higher beds.

The area of sedimentary rocks in French Equatorial Africa included in the two embayments is approximately 50,000 square kilometers (18,000 square miles). The wide distribution of oil occurrences and the seemingly favorable structural conditions suggest that more detailed study of the region is justified.

W. B. HEROY

NEW YORK, NEW YORK
June 27, 1931

The Geology of Malaya. By J. B. SCRIVENOR. MacMillan and Company, Ltd., London (1931). 214 pp., with a colored geological map, scale 12 miles to 1 inch. 6 × 9 inches. Price net, 16 s.

This very attractive book describes an area in which oil is not expected in large quantities. On page 191 only are occurrences of oil noted. "Mineral oil has only been found in shale associated with the coal in Selangor, at Enggor, and in Perlis. The amount is too small to repay distillation and the lighter oils are absent." Selangor is one of the Federated Malay States on the west coast of the Malay Peninsula.

SIDNEY POWERS

TULSA, OKLAHOMA
June 27, 1931

The Auto-Traction Hypothesis of Crustal Evolution, by JUSTIN SARSFIELD DE-LURY. Contribution from the Department of Geology and Mineralogy, University of Manitoba, Winnepeg, Canada (1931), 21 pp.

This hypothesis compares the earth's crust with a continental ice-sheet in which there is flowage between immovable layers above and below.

> Toward the outer edge of an ice-sheet, the sheet being thrust along the bottom may exert so much friction on the rigid top layer that the tensile strength of the carapace is overcome, a crevasse is formed, and the portion of the carapace between the crevasse and the margin is carried along by the bottom sheet. This phenomenon is named auto-traction.

Sheet flow is

> the most probable mechanism for isostatic adjustment.

> The moving sheet may drag one part of the carapace away from the main body, forming a rift, or may thin the crust locally and form normal faults, or it may meet an obstacle or an opposing current and produce mountain folding or thrust-faulting.

The author has evidently been influenced by the Taylor-Wegener hypothesis.

Auto-traction may be, by definition, the mechanism of movement within a continental ice-sheet which is free to spread in all directions, but the reviewer is at a loss to comprehend how this mechanism applies to deformation of the outer rigid crust of the earth, nor does he find any plausible explanation in the author's unsupported statements and applications.

SIDNEY POWERS

TULSA, OKLAHOMA
July 9, 1931

"Deep Wells of Nebraska," by G. E. CONDRA, E. F. SCHRAMM, O. L. LUGN. *Nebraska Geol. Survey Bull. 4*, 2d Ser. (1931). 288 pp., 7 figs. 9¾ × 6¾ inches.

This comprehensive and invaluable report is divided into five main sections: Introduction, Drilling Methods, Leases and Contracts, Logs of Wells, Pre-Cambrian Wells.

The introduction (17 pages) discusses the work of the Survey in relation to drilling wells, and gives a resumé of the geology of Nebraska.

Approximately 90 wells have reached depths of 1,000 feet or more. The deepest is 5,697 feet, drilled by the Prairie Oil and Gas Company in Banner County, in the extreme western part of the state. Eleven or twelve wells have been drilled to pre-Cambrian rocks, and four or five to granite.

A bill passed by the Nebraska legislature in 1921 places the duty of securing and preserving well logs and the collection and study of cuttings and cores under the Conservation and Survey Division of the University. The Division requires reports from, and coöperation with, those who drill the deep wells. Operators of deep wells are required to take cuttings at 10-foot intervals. A reward of $15,000 each is offered for the discovery of oil and gas in commercial quantities in the state. A bill is before the legislature to increase this amount.

The Survey coöperates with operators as follows: (1) all geological information on file is made available, (2) the elevation of the well is determined, (3) wells are inspected from time to time, (4) cuttings are studied, (5) water samples are analyzed, (6) the operator is assisted in determining the age of strata and probable depths to objective horizons, (7) a detailed log is prepared for each well. This bulletin is largely a compilation of such logs.

Rock formations.—Most of Nebraska is mantled by Tertiary and Pleistocene beds, including glacial drift and loess in the eastern part, and dune sand; sand, gravel, and clay formations, elsewhere; and alluvium. The bed-rock subdivisions, named from youngest to oldest, are: (1) Cretaceous (Laramie, Pierre, Niobrara, Carlile, Greenhorn, Graneros, Dakota); (2) Cretaceous?-Jurassic? (Morrison?, Sundance); (3) Permian?-Triassic? (Spearfish); (4) Permian (Big Blue); (5) Pennsylvanian (Missouri, Des Moines). Systems which do not crop out are: Mississippian, Silurian, Ordovician, Cambrian, and pre-Cambrian.

Pre-Cambrian structure.—Five, possibly six, pre-Cambrian "highs" and five basins are known from the well records. The "highs" are: (1) southeast corner of South Dakota, (2) Nemaha Mountains in southeastern Nebraska, (3) Frontier and Furnas counties, south-central part, (4) Cambridge anticline, and (5) Chadron dome. A questionable "high" occurs near Fremont.
The basins are: (1) between the southeast South Dakota "high" and the "high"? near Fremont, (2) east of the Nemaha Mountains, near the extreme southeast corner of the state, (3) a large basin in central Nebraska, extending throughout more than half the state, (4) a basin in the west part of the state, which is the northern extension of the Denver basin, and (5) the McCook syncline between "highs" 3 and 4.

Granite has been reached at comparatively shallow depths in "highs" 2 and 3. Other pre-Cambrian rocks, including quartzites and schists, have been found on "highs" 2 and 5. The basins and "highs" are modified by anticlines and faults.

The second section (12 pages) discusses drilling methods, leases, and contracts.

The third section (243 pages) contains detailed records of practically all the wells deeper than 1,000 feet, and many from adjacent Iowa, Missouri, and Kansas. Some records were made from drillers' logs, others from cuttings. Correlations are given.

The fourth section (6 pages) discusses pre-Cambrian wells.

The bulletin contains seven figures, including a map of the bed-rock formations, pre-Cambrian "highs" and "lows," derrick and drilling outfits, a map showing the location of deep wells in Nebraska, a cross section of gas wells at Crawford, Dawes County, in the northwest corner of the state, and a map of pre-Cambrian wells in seven states.

The data contained is most complete and furnishes almost all the information needed for a study of the subsurface geology of Nebraska. The structural geologist, the stratigrapher, the paleogeographer can ask for little more except further drilling and similar information on future wells.

ROBERT H. DOTT

TULSA, OKLAHOMA
July 6, 1931

Les roches sedimentaires de France. Roches siliceuses (The Sedimentary Rocks of France. Sliiceous Rocks). By LUCIEN CAYEUX. Ministere des Travaux Publics, Paris, (1929). Memoires pour servir a l'explication de la carte geologique detaillée de la France. May be obtained through G. E. Stechert and Company, 33 East Tenth Street, New York. 774 pp., 30 pl.

Sedimentary rocks are classified as siliceous, calcareous (and dolomitic), argillaceous rocks, and rocks resulting from exceptional development of accessory elements. Siliceous rocks are the subject of this first of a series which M. Cayeux is publishing. Those who have read his earlier volume, *Introduction a l' étude petrographique des roches sedimentaires*, have already become acquainted with the excellence of his work.

Avowedly this is not a petrographic manual. A knowledge of such technique is presupposed and necessary. The trained petrographer, however, will find it a very valuable addition to his library and will await with great interest the succeeding volumes.

MARGARET C. COBB

NEW YORK CITY, NEW YORK
June, 1931

RECENT PUBLICATIONS

ALSACE

"Interpretations des anomalies gravimétriques et magnétiques de l'Alsace" (Interpretation of Gravimetric and Magnetic Anomalies in Alsace), by J. Jung and C. Alexanian. *Annal. de l'Office des Combustibles Liquides* (Paris), No. 1 (January-February, 1931), pp. 43-58, 4 figs.

AUSTRIA

"Der neue Ölaufschluss von Kierling bei Wien" (The New Showing of Oil at Kierling near Vienna), by Lukas Waagen. *Intern. Zeits. f. Bohrtecnik, Erdölbergbau und Geologie* (Vienna), No. 12 (June 15, 1931), pp. 89-91, 1 fig.

GENERAL

"Gewinnung des Erdöls durch Bohren" (Drilling Methods in Petroleum Recovery), by K. Glinz, assisted by H. Wolff. *Gewinnung des Erdöls*, Band III, Teil 1. S. Hirzel, Leipzig C I, Germany (July, 1931). xvi + 380 pp., 250 figs. Size, 8vo. Paper, approximately RM. 42; cloth, approximately RM. 45.

Elements of Geology, with Special Reference to North America, by William J. Miller. D. Van Nostrand Company, Inc., New York (1931). 495 pp., 330 figs. 8½ × 5¾ inches. Blue cloth. Net price, $3.00.

A Descriptive Petrography of the Igneous Rocks, Vol. 1, Introduction, Textures, Classifications, and Glossary, by Albert Johannsen. The University of Chicago Press (1931). 267 pp., 145 figs. Price, $4.50.

"Méthodes de l'application de l'avion et de la photographie aérienne aux recherches géologiques" (Methods of Application of Aviation and Aerial Photography to Geological Research), by Stanislas Zuber. *La Revue Pétrolifère* (Paris), No. 430 (June 27, 1931), pp. 813-15.

"Fuel and Combustion Engineering," *Proc. World Engineering Congress* (Tokyo, 1929), Vol. 32 (1931). 21 papers (Section 10 of the Congress), including "The Origin and Constitution of Oilshale, with a Practical Application," by E. H. Cunningham Craig. In English and French. 353 pp., illus. 7 × 10 inches. Cloth. Distributed by Kogakkai, Marunouchi, Tokyo.

"Mining and Metallurgy, Part 5 (Mineral Resources and Mining)," *Proc. World Engineering Congress* (Tokyo, 1929), Vol. 37 (1931). 31 papers (Section 11 of the Congress), including "Petroleum Production Engineering," by J. B. Umpleby; "Petroleum," by Mark L. Requa; "The Permeability of Oil Influencing the Recovery of Petroleum from Unconsolidated Sands," by T. Otagawa; "Statistical Investigations of Production of Oil Wells in Japan," by S. Nomoto; "Activities of the Italian State Railways in the Search for Oil in Albania," by P. Verani. In English, German, French, and Japanese. 712 pp., illus. 7 × 10 inches. Cloth. Kogakkai, Marunouchi, Tokyo.

GEOPHYSICS

"Physics of the Earth—II. The Figure of the Earth," by leading scientific men in several branches of geophysics, treating of the size and shape of the earth. *National Research Council Bull. 78* (February, 1931). National Academy of Sciences, Washington, D. C. 286 pp., 46 figs. 9¾ × 7 inches.

Principles and Practice of Geophysical Prospecting, edited by A. B. Broughton Edge and T. H. Laby. The report of the Imperial Geophysical Experimental Survey. Cambridge University Press, London (1931); The MacMillan Company, New York. xiv + 380 pp., 261 illus. Price, 15 s. net.

"Régeles pratiques pour l'emploi du magnétomètre dans les prospections géophysiques" (Practical Rules in Using the Magnetometer in Geophysical Prospecting), by M. C. Alexanian. *Annal. de l'Office des Combustibles Liquides* (Paris), No. 4 (July-August, 1930), pp. 677-702.

"Correction topographique relative a l'emploi de la balance de torsion" (Topographic Correction in Using the Torsion Balance), by C. Alexanian, geophysical engineer (École Nationale Supérieure du Pétrole, Paris). 4 pp.

"Procédé de prospection géothermique" (Method of Geothermal Prospecting), by C. L. Alexanian. *L'Hydrocarbure*, No. 10, p. 27. Extract from

C. L. Alexanian, *Traite pratique de prospection geophysique* (Geophysical Prospecting). Chez Libraire Polytechnique Ch. Béranger, 15 Rue des Saints-Pères, Paris.

GERMANY

"Present Production and Future Possibilities of Oil in Germany," by Ed. Bloesch. *Intern. Petrol. Tech.*, Vol. 8, No. 7 (Cleveland, Ohio, June, 1931), pp. 285-88, 3 illus.

"Göttinger Beiträge zur saxonischen Tektonik II" (Göttingen Contributions on Saxony Tectonics), under the direction of Hans Stille. *Prussian Geol. Survey Paper*, N. Ser., Vol. 116 (1930). 237 pp., illus.

KANSAS

"The Fauna of the Drum Limestone of Kansas and Western Missouri," by Albert Nelson Sayre. *State Geol. Survey of Kansas Bull. 17* (1931). University of Kansas, Lawrence. 129 pp., 21 pls.

POLAND

"Le champ de gas de Daszawa en Pologne" (The Daszawa Gas Field, Poland), by O. C. Wyszinski. *La Revue Pétrolifère* (Paris), June 20, 1931, pp. 785-86, 3 figs.

SALT DOMES

The following papers appear in the June, 1931, issue of *The Journal of the Institution of Petroleum Technologists* (London).

"Origin of the Salt Domes of the Gulf Coastal Plain of the United States," by E. DeGolyer. Pp. 331-33.

"Moot Points in Salt Dome Theory," by Launcelot Owen. Pp. 334-37; 1 fig.

"A Contribution to 'Salt Dome' Geochemistry," by Murray Stuart. Pp. 338-45.

"Salt Occurrences in Egypt," by Harold Dabell. Pp. 346-48.

"The Salt Dome Area West of Celle, Germany," by Carl Schmidt. Pp. 372-75; 5 figs.

"Salt Dome Studies by Geoelectrical Methods," by Karl Sundberg. Pp. 376-80; 4 figs.

"Geophysical Investigation Carried out in the Salt Dome Areas of the Gulf Areas of the Gulf Coast of Texas and Louisiana," by Carl Schmidt. Pp. 381-83.

TEXAS

"The East Texas Oil Field," by A. I. Levorsen. *Intern. Petrol. Tech.*, Vol. 8, No. 7 (Cleveland, Ohio, June, 1931), pp. 261-68, 6 figs.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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EXECUTIVE COMMITTEE MEETING, TULSA, JULY 12, 1931

The executive committee met at Tulsa, Oklahoma, July 12, 1931. Members present were: president L. P. Garrett, Houston; past-president Sidney Powers, Tulsa; second vice-president Frank R. Clark, Tulsa; and third vice-president F. H. Lahee, Dallas. In addition to other matters of business considered, the committee made preliminary plans for the seventeenth annual meeting at Oklahoma City, Oklahoma, March 17, 18, and 19, 1932. Irving Perrine, of Oklahoma City, is general chairman of the convention.

It was decided to increase the price of *Theory of Continental Drift* after September 1, 1931, from $3.50 to $5.00 a copy. The edition of this rapidly selling book is almost exhausted. After January 1, 1932, the price of *Structure of Typical American Oil Fields*, Vols. I and II, will be increased from $4.00 to $5.00 a copy to members and associates and will be increased from $5.00 for Vol. I and $6.00 for Vol. II to $7.00 each to non-members.

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Memorial

IVY ALLEN KEYTE

Ivy Allen Keyte died at his home in Colorado Springs, Colorado, on May 29, 1931, of a heart attack.

Professor Keyte was born on June 11, 1878, in Macon County, Missouri. He received his early education at Still's School of Osteopathy at Kirksville, Missouri, and practiced there until the age of 27, when an injury to his arm brought this practice to a close. He received the degree of bachelor of pedagogy in 1903 and the degree of master of pedagogy in 1907 from the Missouri State Normal School. He was granted his bachelor's degree in education in 1909 from the University of Missouri. He moved to Colorado in 1912 and taught geology at the State Normal School at Gunnison, becoming president of that institution the following year. In 1915 he was appointed instructor at Colorado Springs High School and part time instructor at Colorado College where he revived the geology department. He was appointed assistant professor of geology at Colorado College in 1919, associate professor in 1922, and professor of geology in 1926. He was granted his master's degree from Missouri University in 1925.

Those who were fortunate enough to be associated with Professor Keyte feel very keenly the loss of a loyal friend, an enthusiastic scientist, and an indefatigable worker. He had the true scientist's attitude as a seeker after the truth and was a stout defender of his own convictions although he was always first to recognize the necessity of changing his views when satisfactory evidence was presented. He was generous in his appreciation of the efforts of others. He had the affectionate regard of his students, who looked to him, not only as a teacher, but also as a friend and adviser.

Only a few days before his death, Professor Keyte discussed enthusiastically with the writer his plans for the future, which included an extensive field trip with his students through the Rocky Mountain region and the completion of several papers for publication. The results of some of his work will eventually be published, but it is greatly to be regretted that he was not spared to complete the tasks he had allotted himself. He had amassed a great deal of paleontological data on the Pennsylvanian of the Rocky Mountain region and was one of the country's foremost authorities on crinoids.

Professor Keyte was elected to membership in The American Association of Petroleum Geologists in 1926. He was also a member of the Paleontological Society of America, the Society of Economic Paleontologists and Mineralogists, Sigma Xi, Sigma Gamma Epsilon, and Delta Epsilon. He is survived by his wife, Ada Ross Keyte and by four sons, Wilbur Ross, Max Allen, Donavan Wayne, and Jack Branson.

Ross L. Heaton

Denver, Colorado
July, 1931

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

Employment

The Association maintains an employment service at headquarters under the supervision of the business manager.

This service is available to members and associates who desire new positions and to companies and others who desire Association members and associates as employees. All requests and information are handled confidentially and gratuitously.

To make this service of maximum value, all members and associates in the Association are requested to coöperate by notifying the business manager of openings available.

H. R. Van Gilder, who has recently completed his graduate work at Yale for the master's degree in geology, has taken a position with the United Gas Products Company with headquarters at Wellsboro, Pennsylvania.

Harold C. Cave may be addressed at Box 2097, Denver, Colorado.

W. G. Woolnough, geological adviser to the Commonwealth Government, Canberra, Australia, who visited the oil fields of North and South America last year, defends his opposition to unscrupulous and unscientific methods in the search for oil in Australia in a statement "Search for Oil" published in the *Sydney Morning Herald*, May 9.

Forrest J. Miller is with the Arkansas Natural Gas Corporation, Shreveport, Louisiana.

Kent L. Kimball, consulting geologist, Hunt Building, Tulsa, Oklahoma, invites attention of field geologists particularly to an article "False Security" by R. R. Ozmer in *Field and Stream* for November, 1930. The warning is: "Beware of snake-bite remedies. The *mechanical removal of the poison* is the only sure cure."

Frank P. Tallman, recently with the Mid-Kansas Oil and Gas Company in West Texas, is in the employ of the Pennsylvania Light and Power Company at Wellsboro, Pennsylvania.

Sigma Gamma Epsilon, the national honorary geological fraternity, has accepted the petition of the Geological Society of Texas Technological College, and eighteen members of the group were recently initiated as charter members of the college's chapter of the fraternity.

Walter Scott Adkins, geologist, Bureau of Economic Geology, University of Texas, has been granted a John Simon Guggenheim Memorial Founda-

tion research fellowship for the preparation of a work on the Lower Cretaceous of the United States; study of type material in European collections.

W. STORRS COLE, recently on the geological staff of the Sun Oil Company at Dallas, Texas, has accepted the position of instructor in physiography at The Ohio State University, Columbus, Ohio, for the coming college year.

HARRY X. BAY, who completed his work June 1 at the University of Iowa, for the doctor's degree in geology, may be addressed at Cole Camp, Missouri.

WILLIAM A. CLARK, JR., who has completed geological work for The Empire Companies in eastern Oklahoma, may be addressed at Chelsea, Oklahoma.

ROBERT WESLEY BROWN, formerly with the Producers and Refiners Corporation, Tulsa, Oklahoma, has accepted the position of professor of geology at St. Lawrence University, Canton, New York, for the coming college year.

J. J. GALLOWAY, associate professor of paleontology at Columbia University, where he has been for the past 15 years, has resigned to accept the chair of professor of geology and paleontology at his Alma Mater, Indiana University. He will continue his work in stratigraphy and micropaleontology in his new position. After September 1, his address will be, Indiana University, Bloomington, Indiana.

LON D. CARTWRIGHT, JR., formerly geologist in charge of operations for the Superior Oil Company of California, in the Permian Basin and Edwards Plateau, is now engaged in private work, principally in east Texas. His present mailing address is San Jacinto Building, Beaumont, Texas.

R. N. FERGUSON and R. SIMMONS, Subway Terminal Building, Los Angeles, announce that H. T. BECKWITH, formerly chief geologist of the Indian Territory Illuminating Oil Company, has become associated with them under the firm name of Ferguson, Beckwith and Simmons, petroleum engineers and geologists.

FRANK W. DEWOLF, vice-president and general manager of the Louisiana Land and Exploration Company, Houston, Texas, is resigning September 1, to become head of the department of geology and geography of the University of Illinois, following Professor W. S. Bayley, who is retiring. Mr. DeWolf was state geologist of Illinois for 15 years. PAUL T. SEASHORE, formerly field superintendent and assistant manager of the Louisiana Land and Exploration Company, will succeed Mr. DeWolf as vice-president and general manager.

MARVIN LEE, consulting geologist, 612-618 Brown Building, Wichita, Kansas, has been appointed chairman of the oil advisory committee to the Public Service Commission of Kansas. Mr. Lee's duties include work with operators regarding the Kansas Ratable Taking Law and making recommendations to the Commission if necessary.

At the regular monthly meeting of the San Antonio Geological Society, June 1, Lieut. Commander S. YOUNG, U. S. N. R., gave an illustrated lecture: "The Story of the First Boat Trip up through the Canyons of the Rio Grande in the Big Bend with the First Pictures of the Interior."

WALLACE E. PRATT, director of the Humble Oil and Refining Company, addressed the San Antonio Geological Society, July 6, on: "Do We Find Oil Fields and How?"

ROY G. MEAD, consulting engineer and geologist, with offices at 1220 Chapman Building, Los Angeles, California, has an article entitled "A Brief History of Kettleman Hills" in the July, 1931, issue of the *Oil Bulletin*.

HARRY HOTCHKIN, geologist, Tulsa, Oklahoma, has an article in the July 18, 1931, issue of *The Saturday Evening Post*, entitled "Hitting the Shore Line."

The West Texas Geological Society held a meeting Saturday, July 11, on the roof of the St. Angelus Hotel, San Angelo, Texas. JOHN I. MOORE spoke on "The Oil Fields of Southern Indiana."

E. G. WOODRUFF, consulting geologist, Tulsa, Oklahoma, has an article in the June 25, 1931, issue of *The Oil and Gas Journal*, entitled "East Texas Oil along Old Shore Line."

FRANK P. DONOGHUE, formerly chief petroleum engineer for the Southern Crude Oil Purchasing Company, was elected president of that company at a recent meeting of the directors. A. L. SELIG, chief geologist, was elected vice-president and director.

RALPH E. DAVIS, consulting engineer, Pittsburgh, Pennsylvania, has closed his Tulsa office and moved the office files to the home office in Pittsburgh.

H. K. SHEARER, geologist for the Standard Oil Company of Louisiana, gave a paper, "Notes on the Correlation and Nomenclature of the North Louisiana Formations," at the May meeting of the Shreveport Geological Society.

CHARLES M. RATH has changed his address to 1254 Cook Street, Denver, Colorado, after more than 12 years in the geological department of the Midwest Refining Company with headquarters at Denver on Rocky Mountain geological and appraisal work.

CLARENCE J. KNUTSON, geologist for Ralph E. Davis Company at Tulsa, will be in the home office of that company at Pittsburgh, following the closing of the Tulsa office.

N. W. BASS resigned from The Pure Oil Company, June 5, and was reinstated on the staff of the U. S. Geological Survey, Washington, D. C. He is stationed at Wichita, Kansas.

CLARENCE J. PETERSON, of the Texoma Natural Gas Company at Kansas City, Missouri, has been transferred to the Amarillo, Texas, office of that company.

P. S. HAURY, geologist, Smackover, Arkansas, has an article in the July, 1931, issue of *The Petroleum Engineer*, entictled "Subsurface Engineering in the Completion and Production of Oil Wells."

E. Hazen Woods is now with the Superior Oil Company of California, with offices at 715 Thomas Building, Dallas, Texas.

E. A. Starke and Louis Chappius, consulting geologists of Los Angeles, realized success as the result of their geological work when the Los Anamos field in Santa Barbara County, California, was discovered last June.

Lowell K. Mower, formerly with the Shell Petroleum Corporation at Dallas, Texas, is now with the Bataafsche Petroleum Maatschappij, 30 Carel van Bylandtlaan, The Hague, Holland.

Herschel H. Cooper, consulting geologist and president of the San Antonio Section of the Association, was injured by the collapse of a derrick in Lavaca County, Texas, July 8.

Theory of Continental Drift, an Association publication the edition of which is almost exhausted, can be purchased at $3.50 a copy until September 1, 1931, after which the price will be $5.00.

Structure of Typical American Oil Fields, Vols. I and II, will be available until January 1, 1932, at $4.00 per copy to members and associates; and $5.00 for Vol. I and $6.00 for Vol. II to non-members. After January 1, the price of each will be $5.00 to members and associates and $7.00 to non-members.

Frith C. Owens, formerly district geologist for the Humble Oil and Refining Company at McAllen, Texas, has been transferred to Laredo, Texas, where he will do geological work.

PROFESSIONAL DIRECTORY

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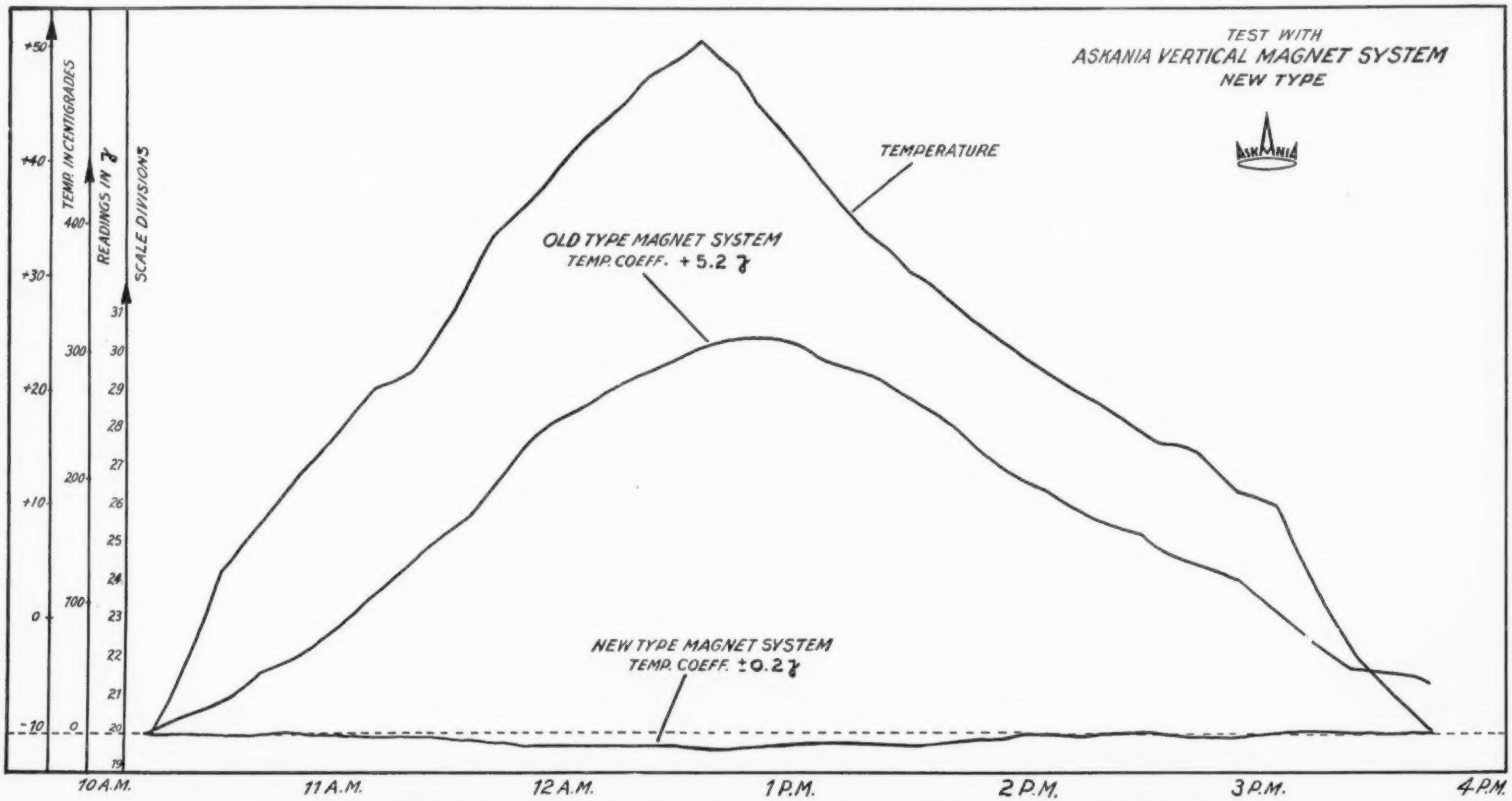

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